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Improving warehouse inventory management through RFID, barcoding and robotics technologies

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MBA PROFESSIONAL REPORT

IMPROVING WAREHOUSE INVENTORY MANAGEMENT THROUGH RFID, BARCODING AND ROBOTICS TECHNOLOGIES

December 2014

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The purpose of this MBA project is to explore the potential value of combining automatic identification and robotics technology in order to improve asset visibility within a warehouse environment. The Defense Logistics Agency (DLA) experiences high costs associated with inventory inaccuracies and annual inventory audits. Our project examines technologies that could be used to improve the DLA's asset visibility. This study examines current industry applications of viable technologies in the marketplace and whether implementing these technologies would provide a sound economic solution. A cost–benefit analysis is included to determine the affordability of efficiencies that RFID and barcoding bring to warehouse operations. This analysis encompasses costs for systems purchase, implementation, and integration. Benefits are measured by determining cost savings in manpower requirements, increased efficiencies in order and restocking times, and improved accuracy in inventory management. The qualitative analysis addresses the advantages and disadvantages of an automatic identification system implementation. It also addresses future potential for the use of robots to improve inventory management. Ultimately, the project concludes that 2D barcoding far more cost effective within 10 years; however, both 2D barcoding and RFID can provide a positive return on investment.

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IMPROVING WAREHOUSE INVENTORY MANAGEMENT THROUGH RFID, BARCODING AND ROBOTICS TECHNOLOGIES

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LIST OF ACRONYMS AND ABBREVIATIONS

1D	one-dimensional
2D	two-dimensional
AIS	automated information system
AIT	automatic identification technology
ALOC	airlines of communications
ASN	automated shipping notice
AT	asset tracing
Auto-ID	automatic identification
AWOS	automatic weigh and offer system
aRFID	active radio frequency identification
COCMS	combatant commanders
DC	distribution centers
DLA	Defense Logistics Agency
DOD	Department of Defense
DORRA	DLA Office of Operations Research and Resource Analysis
EDC	Eastern Distribution Center
FTE	full-time equivalent
FY	Fiscal Year
GAO	Government Accountability Office
GS	General Schedule
HERE	hazards of electromagnetic radiation to ordnance
HF	high frequency
IA	information assurance
ISR	intelligence, surveillance, and reconnaissance
ITV	in-transit visibility
IUID	item unique identification
JTF	Joint Task Force
KVL	Kiva vertical lifts
LCL	lower confidence level

MRO	material release order
NPV	net present value
PMT	positive material transfer
POM	Program Objective Memorandum
QR	quick response
RF	radio frequency
RFID	radio frequency identification
TRL	technology readiness level
UHF	ultra-high frequency
UPC	Universal Product Code
UCL	upper confidence level
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
WAWF	Wide Area Work Flow

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I. INTRODUCTION

A. PURPOSE OF STUDY

The purpose of this MBA project was to analyze whether Radio Frequency Identification (RFID) technology and robotic technology is both mature and reliable enough to integrate in a Defense Logistics Agency (DLA) wholesale warehouse environment. The DLA commissioned the study to explore, discover, and evaluate the potential applications of integrating both technologies to perform inventory functions within their warehouses. Furthermore, they wanted to examine whether the sources of hardware and software would be applicable to the DLA's distribution wholesale warehouse operations.

This study was commissioned to improve asset visibility within the normal operations of a large distribution center. The Government Accountability Office (GAO) has published multiple reports identifying the Department of Defense's (DOD) supply chain management as a high-risk area. These reports focused specifically on the requirement for improvement in material distribution and asset visibility. The DLA is the DOD's primary combat support logistics agency. In providing this support, the DLA experiences high cost associated with annual inventory audits and seeks to improve its asset visibility. In August 2006, nuclear parts were mistakenly sent to Taiwan, which resulted in an investigation into the handling of classified materials in DLA warehouses (White, 2008). Wall-to-wall inventories had to be completed in order to ensure that all the classified parts were accounted for. An official at the DLA Office of Operations Research and Resource Analysis estimated that the DOD spent approximately $13 million to have the inventory performed. Additionally, as small arms weapons are returning from the war zone to armories for repair, storage, and re-distribution, the requirement for 100% accountability is vital. Due to human error, which occurs in shipping and inventory handling, the DLA wanted to explore whether RFID and robotics technologies could be integrated to reduce, if not eliminate, these errors and meet current and future DOD directives on RFID implementation.

This paper presents the findings of a cost–benefit analysis and feasibility study on the use of RFID technology in the DLA's distribution centers to improve inventory management and order processing. In this study, we determined to what extent the problem could be solved and whether RFID is feasible and cost effective or if a combination of alternate technologies provides a better solution.

RFID is a well-established and widely used auto-ID technology that uses electromagnetic frequencies to transmit location data for inventory. The DLA has RFID readers located at warehouse receiving doors but does not utilize RFID beyond the initial receipt process. RFID combined with robotic technology can be an enabler of alternative inventory management processes. RFID allows automated machinery and robots to navigate through facilities, differentiate between inventory items, and provide location information for on-hand inventory.

The use of robotics in manufacturing and in warehouses is not a new concept; however, new technology and methods are being used to increase efficiency and decrease cost. In our research, we explored how robotic technology has improved efficiency and what methodologies were adapted to achieve cost savings and increased efficiency.

Examining industry applications, researching available auto-ID technology, and investigating whether these technologies can provide a sound economic solution for inventory management for the DLA conducted a thorough examination. Industry leaders are using these tools to improve operations, reduce required labor, shorten shipping times, and realize cost savings; therefore, we examined the current technology of robotics, barcodes, and RFID by exploring the various uses throughout their warehouses. Our research considers the advantages and disadvantages of using the different auto-ID technologies for tracking inventory within a warehouse. Additionally, the study provides a cost–benefit analysis to determine whether a combination of robotics and RFID might result in a reduction in manpower requirements, improve inventory management, and increasing efficiency in receipt, order processing, and distribution for the DLA.

II. BACKGROUND

A. SUPPLY CHAIN MANAGEMENT IN THE DEPARTMENT OF DEFENSE

The Department of Defense (DOD) has one of the largest and most complex supply distribution networks in the world. Systems of this magnitude require disciplined supply chain management processes and procedures to ensure maximum efficiency. Recognizing the potential for cost savings, in the early 1990s, Congress directed the Government Accountability Office (GAO) to conduct long-term studies of the DOD's supply chain management (GAO, 2006)

Supply chain management "consists of processes and activities to purchase, produce, and deliver material" (GAO, 2009, p. 8). The DOD is especially complex due to the wide variety of part types, equipment, fuels/liquids, and types of ammunition that must be managed and distributed. Across multiple reports on weaknesses in the DOD's supply chain management, the GAO developed multiple recommendations for improvement. Throughout the last 13 years, in an effort to improve the operational capabilities of troops in Iraq and Afghanistan, the DOD has focused primarily on the management and distribution of spare parts and supplies (GAO, 2009).

B. DEFENSE LOGISTICS AGENCY

As the largest distributor of parts, supplies, and equipment, maintaining an accurate inventory is a top priority for the Defense Logistics Agency (DLA). Under the supervision of the under secretary of defense for acquisition, technology, and logistics (USD[AT&L]), the DLA serves as the DOD's combat logistics support center and focuses on improving military readiness by positioning material closer to customers. Operating in 48 states and 28 countries, the DLA is one of the largest distributors of parts, equipment, and supplies across the DOD (DLA, 2014). The DLA processes approximately 1.2 million requisitions annually while managing six million lines of equipment and supplies. It experiences multiple challenges in inventory management and order processing, resulting in high associated costs. The DLA operates 25 distribution centers around the world: 17 locations in the continental United States and eight outside of the continental United States. The DLA's two major stateside distribution centers are located in Susquehanna, PA, and San Joaquin, CA (DLA, 2014).

The DLA has taken multiple steps to implement in-transit visibility technology into its supply chain management system; however, the agency has not fully recognized whether Radio Frequency Identification (RFID) systems for asset tracking would improve current inventory management processes. Table 1 represents the obligations for new technologies.

Table 1. Defense Logistics Agency Obligations for New Technologies (from GAO, 2013)

Defense Logistics Agency Efforts in Millions			
Effort and Description	**OBLIGATIONS FY 2009–2011**	**PROJECTED COST FY 2012–2015**	**Total**
Passive Radio Frequency Identification (RFID) Visibility for the Department of Defense (DOD) Improvements to an existing system that provides in-transit visibility of cargo using passive RFID (Undertaken in response to 2004 OSD Memo)	0.5	-	0.5
Passive Radio Frequency Identification (RFID) Receiving (PRR) Program An enhancement to an existing cargo receiving process that uses passive RFID to improve the quality of data and process efficiency for cargo arriving at distribution depots.	4.9	0.4	5.3
Active Radio Frequency Identification (aRFID) Migration A program designed to move the active RFID enterprise from a proprietarily air interface protocol to an open standard (TRANSCOM, the service and DLA)	0.2	0.1	0.3
Materiel Receipt Asset Tracking Improvements to a warehouse system that provides enhanced inventory controls from receipt of cargo to storage	0.1	-	0.1
Positive Material Transfer (PMT) A program to improve a system that provides in-transit visibility of cargo from a distribution depot to the point of delivery. (DLA, Air Force)	0.3	0.2	0.5
Clothing and Textile Military Uniform Program A program that improves the quality of inventory management data used to track initial issuance of military uniforms. (DLA, the services)	0.2	1.5	1.7

C. THE ASSET VISIBILITY PROBLEM

Asset visibility, as it applies to the DOD, is the systematic tracking of all supply items used for supporting operations in garrison, training, and operations abroad. The DOD uses asset visibility to optimize the supply chain in order to more efficiently and effectively accomplish supply chain operations. Defense logistics is a detailed process, and

> supply chain management in DOD is not limited to the physical aspect of buying, receiving, storing, or transporting items but also requires the capturing, managing, integrating, and sharing the related information about the item itself, whether it is in-storage, in-transit, in-process, or in theater. (DOD, 2014, p. 9)

Asset visibility includes asset tracking (AT), in-transit visibility (ITV), and Item Unique Identification (IUID) for life-cycle management of assets.

As the scope of the DOD's mission has broadened across the globe, the need to provide increasingly complex logistical support has also increased. While fulfilling these requirements, defense logistics agencies have continuously expanded their knowledge base, and as a result, "DOD introduced visibility capabilities and automatic identification technology (AIT) to improve the ability to track assets as they progressed from unit stations and from industry, stored in distribution locations, and flowed through the transportation system into theater" (DOD, 2014, p. 6).

Combatant commanders (COCOMS), Joint Task Force (JTF) commanders, the services, and other DOD components benefit from the ability to track supplies needed for mission success. Maintaining effective asset visibility allows decision-makers to know where an item is and when it will arrive, allowing better planning and execution of operations. In the joint environment, it is also imperative that all DOD branches and supporting agencies coordinate their efforts and employ the same tools in order to maximize efficiency, avoid duplication of effort, and ensure a fully integrated system.

Between 2004 and 2013, under direction from Congress to conduct studies on the DOD's asset visibility, the GAO published several reports on the results, focusing on inventory management, forecasting requirements, asset visibility, and material distribution for the DOD. The intent of these reports was to identify systemic weaknesses and recommend a plan that would increase efficiency and ensure timely delivery of supplies to globally deployed forces (GAO, 2009; GAO, 2011). The GAO recommended several methods, one of which would be the use of radio frequency identification (RFID; GAO, 2013).

In September 2005, the DOD issued the Enterprise Transition Plan, which highlighted material visibility as one of six priorities to improve the performance of the supply chain. Testimony was provided by William M. Solis, director, Defense Capabilities Management, to the Subcommittee on Oversight of Government Management and U.S. Senate, as noted in the GAO (2006) report *DOD's High Risk Areas: Challenges Remain to Achieving and Demonstrating Progress in Supply Chain Management.* In his testimony, Director Solis defined *materiel visibility* as "the ability to locate and account for materiel assets throughout their life cycle and provide transaction visibility across logistics systems in support of the joint warfighting mission" (GAO, 2006, p. 14). RFID implementation is one of the solutions identified as a method to address this priority and achieve the goal of increased asset visibility.

The DOD released the 2007 Enterprise Transition Plan to use as a roadmap for the department's business transformation. This plan identified total asset visibility as a key focus in improving supply chain operations. The plan stated, "RFID will improve process efficiencies in shipping, receiving, and inventory management, contribute to reductions in cycle time, and increase confidence in the reliability of the DOD supply chain through increased visibility of the location of an item or shipment" (GAO, 2009, p. 10). However, by 2009, the GAO had once again thoroughly investigated the DOD's supply chain practices to see whether RFID had been implemented and whether it was providing increased visibility in tracking location and movement of supplies within the chain. They found no way to demonstrate whether the benefits of the DOD's usage of RFID justified the cost. The GAO (2009) noted that the "DOD does not collect detailed data on implementation costs or performance-based outcome measures from initial implementation efforts that would enable the department to fully quantify the return on investment associated with these two technologies" (p. 7).

The DOD responded by releasing the *DOD Plan for Improvement in the High Risk Area of Supply Chain Management with a Focus on Inventory Management and Distribution*. In this plan, the focus areas included asset visibility, forecasting, and distribution, all of which can be improved with implementation of RFID. In examining RFID, the plan stated as an expected outcome,

> RFID is a transformational technology and will play a vital role in achieving the DOD vision for implementing knowledge-enabled logistics support to the war-fighter through fully automated visibility and management of assets. RFID will directly enable the sharing, integrating, and synchronizing of data from the strategic to the tactical level as the advance ship notices are forwarded to the nodes in the supply chain. (DOD, 2009, p. 6)

Although the DOD considered RFID a priority and identified it in various improvement plans for supply chain improvement, when the GAO again examined the DOD's implementation, they found DOD adherence to policy lacking. The GAO's report titled *DOD Needs to Take Additional Actions to Address Challenges in Supply Chain Management* determined that the "DOD has not established performance measures to assess the impact of its implementation, despite the significant initial investment of resources required to use the technology" (GAO, 2011, p. 26).

The DOD responded, stating the current plan in place would address these concerns; however, the GAO conducted another study in 2013. After this study, the GAO concluded in the report titled *A Completed Comprehensive Strategy Is Needed to Guide DOD's In-Transit Visibility Efforts* that the DOD had made little progress and was still faced with the same challenges, including

> unmet delivery standards and time lines for cargo shipments; incomplete delivery data for many surface shipments; inadequate radio-frequency identification (RFID) information to track all cargo movements to and within Afghanistan; lack of a common operating picture for distribution data that integrates DOD's many transportation information systems; difficulties in collecting information on all incidents of pilferage of and damage to cargo; and ineffective tracking and managing of cargo containers. (GAO, 2013, p. 3)

The deputy assistant secretary of defense for supply chain integration acknowledged the need for the DOD to refocus its efforts throughout all departments on "measurable actions to improve asset tracking and in-transit visibility using automatic identification technology as an enabler when requirements for end-to-end supply chain optimization dictate its use" (GAO, 2013, p. 15). While the DOD has applied technological solutions, there is no formal mechanism in place where information is consistently shared regarding the efforts to provide and improve asset visibility throughout the supply chain process. During a GAO investigation, they reported that the

> DOD has taken steps to improve in-transit visibility of its assets through efforts developed by several of the defense components, but no one organization is fully aware of all such efforts across the department, because they are not centrally tracked. (GAO, 2013, p. 12)

In the 2014 report, *Strategy for Improving Asset Visibility*, the DOD stated that its strategic vision is for "improved asset visibility, through continuously improving and innovating business processes, resulting in more effective deployment/redeployment, sustainment, and retrograde operations and decisions, and yielding integrated, end-to-end Warfighter support with increased customer confidence" (DOD, 2014, p. 19). In the report, the DOD set the following goals:

- Improve visibility into customer materiel requirements and availability of resources to meet those requirements.
- Enhance visibility of assets in-transit, in-storage, in-process, and in-theater.
- Improve efficiency of physical inventories, receipt processing, cargo tracking, and unit moves.
- Increase inventory existence and completeness in support of audit readiness.
- Enable a single authoritative asset visibility data set that is integrated and accessible to support informed logistics decision making across DOD.
- Implement AIS strategies for improved asset visibility, data integration, and interoperability.
- Deploy AIT (e.g., RFID and 2-dimensional Data Matrix symbols) to capture data about items and shipments for enhanced accuracy, reliability, and timeliness with the least amount of human intervention. (DOD, 2014, p. 9)

To date, the DOD has applied technological solutions:

> With the goal of improving the efficiency and effectiveness of the DOD supply chain, focus to date has been to improve segments of the DOD supply chain to track consolidated shipments in transit using AIT

(including barcodes and active radio frequency identification [aRFID]). (DOD, 2014, p. 7)

To meet the DOD's vision, it is imperative to ensure "end-to-end visibility of assets, from acquisition to transportation, supply, maintenance and disposal, from origin to employment, and all points in between including the point of need" (DOD, 2014, p. 16) to increase efficiency and conduct more effective operations.

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III. TECHNOLOGIES FOR DISTRIBUTION AND ASSET MANAGEMENT

A. RADIO FREQUENCY IDENTIFICATION TECHNOLOGIES

1. Introduction to Radio Frequency Identification

Radio Frequency Identification (RFID) is not a new technology. According to Kitsos and Zhang (2008), RFID was developed in the 1950s; however, it has gone through several technological advances during the past 60 years. The GAO defined RFID as "an automated data-capture technology that can be used to electronically identify, track, and store information contained on a tag" (GAO, 2005, p. 1). RFID systems consist of a transponder, a sensor (reader), and a database that collects and stores data from the reader. The transponder, also known as a tag, consists of two parts, a chip and an antenna. The chip can store detailed information specific to the item to which it is attached. This information can be anything. While serial numbers, National Stock Numbers, production dates, and location are most common, the capacity to store information is only limited by the size of the chip and the speed at which it can be transmitted. The antenna is attached to the chip and transmits the information stored to the reader. The reader is responsible for scanning the tag for the item's stored data and then relaying that information to a database. For example, a tag can be affixed to a pallet. As the pallet transitions within a warehouse, readers detect and pass the information transmitted by the tag to a database that stores all the information, which "can include item identifier, description, manufacturer, movement of the item and location" (GAO, 2005, p. 9). See Figure 1 for an overview of RFID system components.

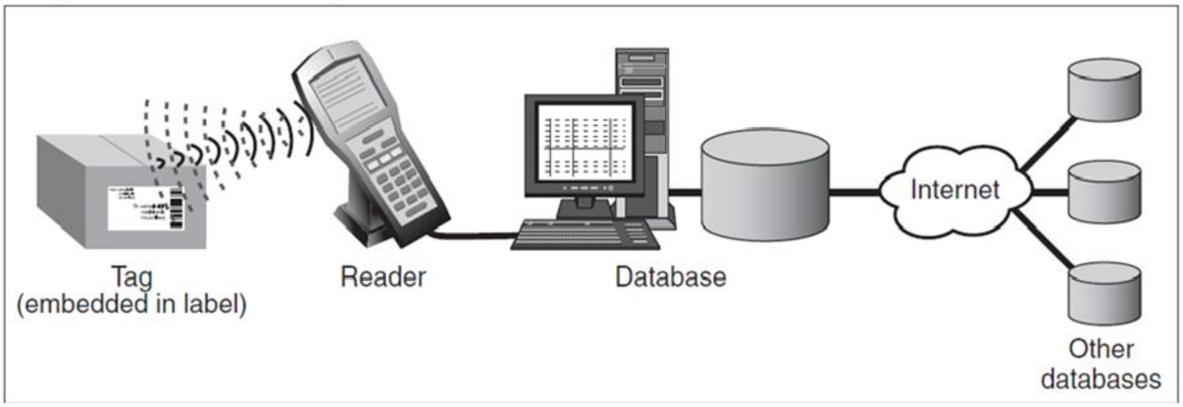

Figure 1. Main Components of an RFID System (from GAO, 2005, p. 5)

RFID tags fall into one of two categories: passive transmission or active transmission. The passive tag lacks its own power source and cannot self-initiate communication with a reader. The tag is powered by the reader's radio frequency and transmits data only when it is within range of the frequency broadcast by a reader. Passive tags are smaller and much cheaper to maintain because they do not require batteries but have a relatively short range. These tags are used for a large number of items within close proximity to readers. Passive technologies receive power from a wide range of frequencies. These frequencies generally fall into four ranges: low, high (HF), ultrahigh (UHF), and microwave (GAO, 2005). Table 2 describes the types of ranges and their frequencies.

Table 2. Common RFID Operating Frequency for Passive Tags (from GAO, 2005, p. 11)

	Frequency	**Typical read range and rate**	**Examples of use**
Low frequency	125 KHz	~1.5 feet; low reading speed	Access control, animal tracking, point of sale applications
High frequency	13.56 MHz	~3 feet; medium reading speed	Access control, smart cards, item-level tracking
Ultrahigh frequency	860-930 MHz	up to 15 feet; high reading speed	Pallet tracking, supply chain management
Microwave frequency	2.45/5.8 GHz	~3 feet; high reading speed	Supply chain management

Active tags contain a power source and transmitter that can send a continuous signal. Active tags are larger than passive tags and have a longer reading range. They are more reliable, and their long reading range makes them more advantageous than passive tags; however, once the batteries discharge, they can lose the capability to transmit a signal.

RFID tags build upon the commonly used industry standard technology of barcodes and magnetic strip cards. Not only can RFID tags hold more information, but they also can be reprogrammed multiple times with new information. Unlike barcodes, the tags do not require line of sight to be read, and operate quickly over larger distances. See Figure 2 for an overview illustration on how RFID works source to destination.

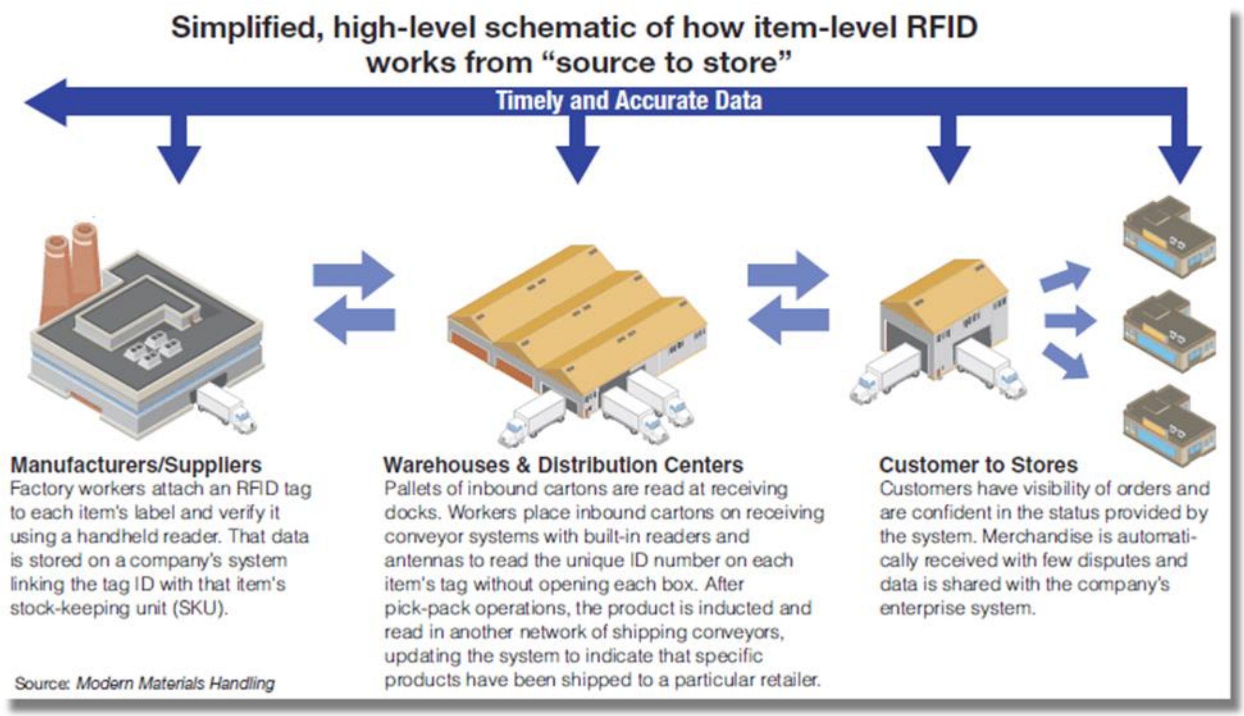

Figure 2. Illustration of How RFID Works (from Napolitano, 2013)

2. BENEFITS OF RFID

When used correctly, RFID technology has the potential to deliver multiple benefits. The GAO reported that "the technology can provide a more efficient method for federal agencies, manufacturers, retailers, and suppliers to collect, manage, disseminate, store, and analyze information on inventory, business processes, and security controls, among other functions, by providing real-time access to information" (GAO, 2005, p. 1). Examples of the use of RFID by industry include, but are not limited to, manufacturing, retail, security, farming, healthcare, and distribution and inventory. In the article "Retailers are Driving RFID Adoption and Propagating the Benefits Throughout their Supply Chains," Napolitano (2013) pointed out that in an

> October 2011 study of 58 suppliers and 56 retailers across North America, conducted by Accenture on behalf of the Voluntary Interindustry Commerce Solutions Association (VICS) and its Item-Level RFID Initiative (ILRI), reports that the technology is at a "tipping point" with more than 50% of retailers and suppliers already piloting or implementing item-level RFID. (para. 3)

Ferrer, Dew, and Apte (2010) analyzed multiple variables to determine the benefits of RFID. They found "that most applications in service industries have four common benefits: replacement of labor through automation, cycle-time reduction, enabling self-service, and loss prevention" (Ferrer et al., 2010, p. 424).

RFID tags can eliminate the need for manual inventories and can assist supply chain managers in keeping accurate inventory measurement on arrival and departure, both at origin and destination. Napolitano pointed out that "inventory accuracy has improved to rates above 95%; the time required for workers to perform cycle counts in stores has decreased by up to 96%; and out-of-stock events have decreased by 50%" (Napolitano, 2013, para. 7). This is extremely important to the DOD, which has long, complex, supply chains. The installation of readers at entrances of warehouses assists with tracking inventory arrival. This can reduce the requirement to physically count every item that enters in the warehouse. By adding multiple mobile or fixed readers within a warehouse, tagging individual items, cases, or pallets provides real-time tracking capability of item movement and can assist with locating misplaced inventory. Readers installed at exit points help ensure accurate tracking of departing inventory. All of these inventory measurement strategies help reduce required labor, item loss, and inventory cycle-time. In the book, *RFID: Applications, Security, and Privacy*, Garfinkel and Rosenberg (2006) indicated that

> this measurement, in turn, enables more efficient change of hands between commercial entities, better traceability of goods, better protection from theft and other malfeasance, and most important, a more stable tightrope walk between the two ills of the supply chain: too much inventory and too little inventory. (p. 41)

Napolitano (2013) pointed out the following benefits that RFID can provide:

- An internal reduction of inventory levels as a result of greater inventory accuracy.

- An increase in speed and accuracy in materials handling operations by substantially reducing the number of touches per carton, resulting in a significant reduction in distribution center (DC)labor cost.

- An increased speed of cycle counts, decreasing the labor required while simultaneously increasing the accuracy of the count.

- A reduction or elimination of manual item-level audits of carton contents, thus minimizing the time and labor associated with the DC receiving process.

- The ability to audit each outbound pick-pack carton quickly to ensure a high degree of outbound accuracy and be able to detect errors before they are found by the customer.

- A reduction in the number of claims or chargebacks by retail customers.

- The automatic ability to create an automated shipping notice (ASN) based on the products in the container and the time of departure of that container.

- The verification of an entire container manifest without needing to unpack the container.

- With consistent, highly accurate performance, it will allow a supplier to completely bypass the retailer’s DC, and instead ship direct to stores, avoiding any need to cross-dock that merchandise at the retailer’s DC.

- A reduction in shrinkage due to customer and employee theft.

- Enable continuous quality improvement and result in fewer return-related costs and markdowns.

- By enabling tracking and tracing, RFID has the potential to reduce the cost of compliance with free trade agreements, governmental mandates and regulations while improving customs processes. (Napolitano, 2013)

3. RFID CHALLENGES TO IMPLEMENTATION

Despite the vast number of benefits that come with the implementation of RFID, the system has very expensive up-front costs for purchase and installation. These costs are not only limited to hardware and software, but also include the cost of training and incorporating new processes for inventory management. These costs are both monetary and cultural. When implementing changes to an organization's established process, it can be difficult to overcome cultural inertia. It is also vital to avoid adapting technology and software to substandard processes. Shepard (2005) pointed out in his book *RFID: Radio Frequency Identification* that "full implementation for a large corporation can become a multi-million dollar venture, and although it will offer an attractive payback if implemented for the right reasons, it is still a significant financial undertaking" (p. 162).

When determining whether RFID is worth the investment, organizations must answer at a minimum the following questions: (1) What are the benefits RFID technology will offer? (2) Will the benefits provide a return on investment? (3) Does the existing infrastructure support the use of RFID, and if not, what changes will be required? Ferrer et al. (2010) noted that "managers continue to struggle with the decision to adopt this technology, trying to select the configuration that is most appropriate for their operational needs and that enhances the operational performance" (p. 414). Furthermore, when analyzing the benefits and cost of investment, Ferrer et al. (2010) suggested,

> RFID Technology should be adopted in service operations only if one or more of the following conditions are satisfied:
>
> - It helps reduce the labor intensity in businesses characterized as mass services.
> - It helps reduce the number of errors caused by the large number of custom work in service shops with the current levels of labor.
> - It helps increase the perceived customization of professional services by providing additional tools to existing labor.
> - It adds new features (usually associated to theft prevention or personal security) to service factories. (p. 424)

When implementing RFID technology, one of the major questions that must be addressed is who actually tags the items, the supplier or the distributor? It is common for distributors to require suppliers to affix the RFID tags to items. Since the price of tags generally falls on the suppliers, they rarely receive the benefits, but often incur the costs. This can burden smaller suppliers who are forced to adapt to the technology in order to continue doing business. If economies of scale are not realized through large orders, the purchase of RFID tags can be significant (GAO, 2005). Standard passive tags can cost as little as $0.30 each, depending on volume, and active tags as much as $50 each. These prices are continually in flux and can be found on the websites of numerous providers.

A thorough examination of the system implementation location(s) must be completed once reaching a decision to adopt RFID. It is important to ascertain how to best utilize the system. This will allow the agency to determine what businesses practices to adopt to complement the system in order to receive the greatest increase in efficiency. Elements of the location(s) will influence where readers will be placed, designation of where the tags will be attached, whether the application requires read/write capability, and the products to which the tags will be attached. It is important to understand that radio waves can also be disrupted or degraded by conflicting electronic interference, metals, liquids, and product densities. These all can cause dead spots that will affect the data being downloaded. For example, if the product is metal, or significant amounts of metal shelving are between the tag and the reader, the metal can block or scatter the signal. Liquids can absorb the signal. Therefore, agencies must perform thoughtful consideration and environmental analysis in order to maximize the efficiency of the RFID system.

Although there are obvious benefits, there is not a set solution for implementing the system. Every implementation scenario can present a different situation with a different solution. Shepard (2005) pointed out that

> there is no question that RFID has an uphill implementation battle to fight for a number of reasons including the cost of deployment, changes in internal system philosophies, and conversion from an entrenched, fully functional product identification technique (barcodes) to RFID tagging. (p. 146)

Forethought and planning are vital to understanding the challenges in the actual implementation of RFID and whether or not the benefits will outweigh the cost.

Another consideration is the reliability of the tags and readers. Tags are not always consistently reliable as they may be defective when manufactured or damaged during shipment, may not work with certain products, and may experience interference with radio waves (GAO, 2005, p. 25). The tags can also interfere with other tags when they are in close proximity, causing the reader to be unable to decipher the signals.

The placement of tags can affect the readers' ability to successfully scan the tags. Considerations to tag placement include areas that risk being damaged during the supply chain process or the ability for a reader to scan an object, case, or pallet that is traveling by forklift or conveyor belt (GAO, 2005, p. 25).

In the report titled *DOD Plan for Improvement in the High Risk Area of Supply Chain Management with a Focus on Inventory Management and Distribution*, the DOD identified the following as the impediments/challenges for RFID:

- POM/Budget cycle dictates timing for internal implementation roll out
- System integration cost
- Spectrum approval for overseas locations
- Hazards of Electromagnetic Radiation to Ordnance (HERO)
- Information Assurance (IA). (DOD, 2009, p. 7)

4. RFID in DOD Supply Chain Management

Though there has been an explosion in applications of unmanned systems in the combat environment in the past 13 years for intelligence, surveillance, and reconnaissance (ISR) and explosive ordinance detection and disposal, very few, if any, applications of robotics have been made in supply chain management. On the contrary, implementation of RFID technology has been directed by DOD policy and is still an underutilized technology resulting in multiple, controversial GAO findings.

The United States Department of Defense Suppliers' Passive RFID Information Guide, Version 15.0, states, "The DOD views RFID as a means to facilitate accurate, automated data capture in support of business processes in an integrated DOD supply chain enterprise" (DOD, n.d., p. 8). Not only does RFID increase efficiency in the DOD, but it also benefits suppliers that support the DOD. Within the RFID Information Guide, some of the benefits highlighted for suppliers include

> improved planning, faster demand responses, reduced Bull Whip Effect, streamlined business process, improved efficiency in the recall of defective items, increased ability to ensure that product(s) remain stocked on DOD shelves, and finally, faster receipt of payments for supplied goods. (p. 7)

Furthermore, benefits highlighted for the DOD included "improved inventory management, improved labor productivity, elimination of duplicate orders, replacement of manual procedures, automated receipt and acceptance, improved inventory and shipment visibility and management, reduced shrinkage, enhanced business processes, and finally, improved asset tracking" (p. 7).

On July 30, 2004, the acting USD(AT&L) signed into DOD policy, direction on the implementation of active and passive RFID for supply chain management. This policy memorandum, titled *Radio Frequency Identification (RFID) Policy,* dictated that "DOD sites where material is associated into cases or pallets will tag the material and supplies at that site with an appropriate passive RFID tag prior to further trans-shipment to follow on consignees" (pp. 2–3). RFID technology was to be utilized to the maximum extent practical in order to provide the right material, at the right time, and in the right condition to the warfighter.

B. BARCODES

1. What Is a Barcode?

Barcoding is a system of identification marking that is read and interpreted by an optical or laser reader to identify the product. Barcodes fall into two categories: one-dimensional (1D) and two-dimensional (2D). 1D barcodes use parallel lines of different widths and spacing to represent characters. 2D barcodes use two-dimensional coding (bars and shapes) that can hold much more data. White, Gardiner, Prabhakar, and Abd Razak (2007) pointed out that “traditional barcoding is coupled with the Universal Product Code (UPC) and every day accounts for billions all over the world” (p. 122). A UPC is a 12-digit barcode that contains the manufacturer’s number, and product identification. The Bar Code News (n.d.) reported that “with an increasing global market, one of the main priorities in business was to establish a series of standards that would improve supply demands in any type of service or chain store anywhere in the world.” Furthermore, they stated that in today’s global economy, “approximately 5 billion of these barcodes are read by scanners in the world every day which allows services and chain stores to track what inventory has been sold and needs to be ordered” (Bar Code News, n.d.). The UPC Bar Code allows every product made in one country to be assigned a barcode containing the product’s specific information to be shipped to another country without having to add additional information. Figure 3 identifies a conventional 1D barcode, and Figure 4 represents a 2D barcode.

Conventional 1D barcode (Code 39)

Figure 3. 1D Barcode (from White et al., 2007)

2D Barcode (PDF417)

Figure 4. 2D Barcode (from White et al., 2007)

2. History of the Barcode

Every product that is purchased in the commercial marketplace has a barcode. Developed in the 1940s, patented in the 1950s, and first implemented by the railroad industry to count railcars in the 1960s, barcodes have been adopted by all industries, from supermarkets to distribution centers. Barcodes have become the global standard for identifying and tracking products (Bar Code News, n.d.).

Today, every product that is produced is assigned a barcode that will identify what the item is and any other pertinent information. This greatly assists retailers in performing inventories, tracking products, and identifying characteristics of the item. Furthermore, it also allows for a decrease in cycle-time across various industries as retailers can scan the item and recover the price for a consumer while simultaneously accounting for the purchase and reducing it from a retailer’s inventory count. In the book *Integrated Inventory Management*, Bernard (1999) wrote that throughout various industries, barcodes “speed up counting processes and nearly eliminate data entry errors” (p. 203). By using barcodes, retailers and distributors can quickly count what they have on hand and spend more time determining where other errors exist and how to correct them.

Barcoding technology itself has not advanced much in the past 50 years. The largest advancement in the barcode has actually been the introduction of the two-dimensional barcode. A Japanese company, Denso Wave, developed the 2D barcode in 1994. Paulson (2011) pointed out that the purpose of this new barcode was to "track vehicle parts through the manufacturing process" (p. 20).

Most technological advances have occurred in the readers. More sensitive optical readers and usage of high accuracy laser readers have drastically increased the range at which a barcode can be read.

3. Barcodes: How They Work

Both 1D and 2D barcodes function under the same principle. The configuration of lines or shapes represents characters, which are deciphered by the "reader." Both barcodes technically have an unlimited number of characters they can contain, assuming unlimited space. For an optical or laser reader to quickly and clearly read the barcode, 1D barcodes are generally limited to 20–25 characters; however, 2D barcodes have allowed the expansion of the amount of data contained from 1,800 to 7,000 alphanumeric characters. As of 2011, there were 20 different types of 2D barcodes with specialized applications and data limitations (Paulson, 2011, p. 20). According to Barcode Software and Information (n.d.), in 2D barcodes, "using the smallest recommended element size of 0.0075 inch wide and 0.010 inch high, the maximum data density in the binary mode is 686 bytes per square inch (106.2 bytes per square centimeter)."

4. 1D Barcodes

Traditional 1D barcodes are linear, a single line of bars encoded in the horizontal width. Increasing or decreasing the width of the label changes the number of characters represented. If increased too widely, the barcode cannot easily be scanned. Though 1D barcodes hold significantly less data than a 2D barcode, they are much more durable. Redundancy in the label can be improved by increasing the height of the label. In the event of tearing or abrasions, only a single readable strip of the barcode needs to remain in order for the reader to accurately identify the item that is tagged.

5. 2D Barcodes

In 2D barcodes, product data are encoded in both horizontal and vertical dimensions using lines, shapes, spaces, colors, and symbols (Paulson, 2011, p. 20). White et al. (2007) explained that "as more data is encoded, the size of the barcode can be increased in both the horizontal and vertical directions, thus maintaining a manageable shape for easy scanning and product packaging specifications" (p. 122). Again, at some point, the width and height become too large to easily scan. The result is more data, but there is also less redundancy built into the tag. Abrasions or tearing can result in lost data within the tag and possible misidentification or complete inability to read.

Both types of barcodes have applications for which they are individually suited. 1D Barcodes are best in low-capacity applications, such as assigning a unique identifier to an item. 2D barcodes are best when there is a requirement to pull data directly from the item.

6. Challenges

Barcodes are essentially line of sight in their operation and require manual manipulation. The Bar Code News (n.d.) reported that although laser readers have greatly increased in their range, greater than 30 feet using long-range laser scanning, the tag must be visible. If items are stacked or thrown in a bin, they cannot be read without manual manipulation of the item, making a completely automated inventory process very difficult. Garfinkel and Rosenberg (2006) pointed out "the result is that every scan of a barcode has a hidden cost associated with it. To a large extent, inventory is still guessed at, often incorrectly" (p. 41). Additionally, some items are simply too small to barcode unless they are in large packaging.

7. Benefits of Barcoding

Use of barcode technology for asset visibility has many benefits that can be realized. Most top distribution companies and DOD agencies already use this technology in some form in their operations.

Printing barcodes is cheap. Barcode printers are a fraction of the cost of RFID printers, and the labels themselves are very inexpensive. When printing in quantity, it generally costs less than $0.02 each for a 2 in. by 4 in. tag. This calculation is based on the average price of an ink cartridge plus the price of a 2,000-label roll, divided by 2,000 labels. This low cost makes it possible to tag every item that arrives in the warehouse for processing and tracking.

Barcodes allow for high speed, accurate data entry, and reading. In the same time that it takes a worker to type two keystrokes, an entire barcode, representing up to 7,000 characters, can be scanned. Additionally, for every 1,000 characters typed by a worker, there are an average of 10 keying errors. Using barcode readers greatly reduces error rates. The Bar Code News (n.d.) stated on its website that with an optical character reader (OCR), there is one error in every 1,000 reads, with LED scanners there is one error in 3,000,000 characters, and with new laser technology, there is one error in approximately 70,000,000 entries. Devices can be mounted or handheld. In the past few years, mobile phones, have become more commonly used to read 2D quick response (QR) codes, though they are much more limited in range.

The Barcoding Incorporated (n.d.) website reported that "barcode systems provide an array of benefits, including operational efficiency, better customer service, and improved visibility of key business information to management." System costs are relatively low as barcode technology is very mature, and there is a substantial market of interfacing hardware and software in existence, which leads to extensive price competition between vendors. Training for workers also has a very low cost. A worker can be trained on how to use the system in less than 15 minutes. Last, in terms of cost effectiveness, "barcode systems have a demonstrated payback period of six to eighteen months, and they provide the highest level of reliability in a wide variety of data collection applications" ("Barcoding Incorporated," n.d.).

C. ROBOTIC TECHNOLOGIES

1. Introduction to Robots

In his book *An Introduction to Robotics: Analysis, Systems, and Application*, Niku (2001) defined robotics as “the art, knowledge base, and the know-how of designing, applying, and using robots in human endeavors” (p. 4). The use of robots in manufacturing and in warehouse management has not only increased the amount of goods a company can manufacture but also increased the efficiency in preparing, processing, and packaging orders for shipment. Robots “are capable of performing many different tasks and operations precisely and do not require common safety and comfort elements humans need” (Niku, 2001, p. 1). Although they are capable of performing a wide variety of tasks, robots can only perform tasks for which they were properly designed.

Niku (2001) listed seven different elements that make up a robot system. These different parts are integrated to make a robot work. These elements include manipulator, end effector, actuators, sensors, controller, processor, and software. Niku (2001) described the elements of a robot system as follows:

- The manipulator is also known as the rover and this is the main body.
- End effectors are the parts located at the last joints that usually serves as the hands of the robots, or the joint that handles objects.
- Actuators serve as the muscles of the manipulators and are controlled by the controller.
- Sensors allow the robot to collect information about how the robot is working and also allow the robot to communicate with other devices.
- The controller controls the motion of the robot.
- The processor is the computer of the robot that acts as the brain. It controls the movement, the speed, and the efforts of the robot.
- Lastly, a robot needs to have software to make it come to life (pp. 6–8).

2. ROBOTIC APPLICATIONS

Wang, Ramik, Sabourin, and Madani (2012) proposed the use of multi-robot systems collaborating to perform logistic functions throughout warehouses. Published in 2012 in the journal *The Industrial Robot*, the authors explored the integration of different types of robots performing various logistics functions such as warehouse management and industrial applications (Wang et al., 2012). Wheeled robots, legged robots, humanoid robots, and network sensors are a few examples of the types of robots that are emphasized as being increasingly integrated across various industries to perform specific functions; however, they have individual behaviors and are individually controlled by a “supervisor,” resulting in limitations in collaboration. The researchers’ goal was to design control strategies for multi-robot systems and develop an intelligent system. This would allow for various types of robots to collaborate by communicating through a wireless network while transporting bulky objects around a warehouse (Wang et al., 2012).

The researchers assembled a multi-robot system that included one humanoid robot, three-wheeled robots that would move in a rigid formation, an overhead moving camera to provide a view of the entire warehouse, and a remote computer supervisor. The supervisor would then compute a path based on the images coming from the camera. Once the path was computed, it would be sent to the humanoid robot, performing the role of the local supervisor controlling the three-wheeled robots.

For the robots to collaborate and navigate, the researchers developed a binary matrix based on the overhead camera picture. After successfully conducting simulations in 21 different rooms and conducting an experiment using real robots, the researchers presented a control strategy and design in which multi-robots systems could be used together with a wireless network. The evidence shows that this system could be used for real applications within the logistics field (Wang et al., 2012).

The authors claimed that multi-robot systems could collaborate and provide greater benefits to a wide range of applications in the logistics field in an autonomous fashion because of the advances in wireless communications and robotic technology. The evidence they presented is the desire for increased efficiency in logistics and the increased presence of multiple types of robots in warehouse operations, pointing out the use of multi-robots by Kiva Systems. In undertaking this research, the authors studied prior research that highlighted various strategies about the control of the formation of robots (Wang et al., 2012).

Currently, Kiva Systems is producing multi-robots to move items around warehouses; however, they are all controlled by a central computer, and when obstacles are present, they send messages back to the central computer. Wang el al. (2012) claimed that they could use different types of robots to move bulky items in a constrained environment by having one person use image processing from overhead cameras to calculate a movement plan to move the robot through a warehouse.

Wang et al. (2012) acknowledged that many problems are associated with maintaining the shape of formations; therefore, they designed their research model to "present only a high level control and we consider that the wheeled robots are able to keep a rigid shape" (p. 252). Although the authors acknowledged the problems maintaining the shape of formations, they did not discuss the different formations used in past studies, nor did they discuss the problems with those formations.

Using a formation that is rigid highlights that "the relative distance between two robots is a constant value and all robots have the same orientation" (Wang et al., 2012, p. 252). Based on this information, one can see how the formation would allow robots to maneuver bulky products through a constrained environment; however, it is still unclear why the authors used this exact formation. The authors attached the binary matrix illustration that described how the camera's images would be turned into a binary representation that would determine the path and where the obstacles were located. This helps to understand how the positioning of the robots would allow a supervisor to look at the images from the camera and be able to compute a path plan for the robot to maneuver around a warehouse.

Wang et al. (2012) stated, "The main problem is how to compute the path planning in order to move the formation from an initial point to a goal point in a constrained environment" (p. 253). They then developed online control for real-time applications and designed a matrix to move the wheeled robots throughout a constrained warehouse. While acknowledging the challenges with computing the plan, a researcher could respond with the argument that they could eliminate the humanoid robot and actually put cameras on the wheeled robots, allowing them to see their environment and maneuver around obstacles.

Wang et al. successfully conducted 21 simulations using the software WEBOTS, and then performed one experiment with real robots to determine whether this could actually work. After performing the experiment, they determined that multi-robots could collaborate and be used successfully in a constrained environment using a wireless network (Wang et al., 2012). This provides solid evidence of its success and identifies potential applications to other situations within the DOD.

Kiva Systems is an industry leader in the use of robots in distribution centers to increase efficiency and reduce cost. Kiva (2014) boasted on its website that by "using hundreds of autonomous mobile robots and sophisticated control software, the Kiva Mobile-robotic Fulfillment System enables extremely fast cycle times with reduced labor requirements, from receiving to picking to shipping." By using autonomous robots, Kiva has been able to transform distribution centers into efficient environments where robots maneuver shelves of merchandise to a packer, rather than using packers to search aisles for products to fulfill orders. In 2013, Amazon.com acquired Kiva Systems for $775 million. Bensinger (2013) pointed out that "Amazon's rollout of robots from a company it bought last year, Kiva Systems Inc., could help pare 20% to 40% off the $3.50 to $3.75 cost of fulfilling a typical order." Kiva System's autonomous robots are now used by industry giants like The Gap, Staples, Saks Fifth Avenue, Office Depot, Crate and Barrel, Gilt Groupe, and Walgreens (Kiva Systems, 2014). Lobosco (2014) reported on CNN Money that Amazon currently has 1,000 robots and "will be using 10,000 robots in its warehouses by the end of the year.

Not only can robots be used to bring products to packers as is the case with Kiva, they also have other functions that can increase efficiency, such as palletizing goods, that frees up human labor for less strenuous, more value-added positions. One could argue that robots are taking well needed jobs that a human could be doing and freeing up labor dollars. This is true; however, robots provide a service of performing strenuous, repetitive, and highly technical error-free jobs that humans simply do not want or simply cannot perform. Bond (2012) argued that "instead of a worker loading and unloading floor-stacked trucks in sweltering heat, a robot might reliably ferry product in and out of a facility around the clock." For every role that a robot takes, it also takes humans to be able to design and program robots to do the work.

D. ROBOTS AND RFID

RFID has emerged as a cost-effective technology that allows for automatic labeling of any type of object or animal and even people. Robotics researchers have now focused their attention on the use of RFID with robots in the area of navigation and indoor mapping. Catarinucci, Tedesco, and Tarricone (2013) explored the use of RFID in the navigation of robots due to its cost and ease of use. They pointed out that "if passive tags are used as landmarks and the robot is equipped with a reader, RFID technology does naturally become a cost-effective support for robot navigation and localization" (p. 783). Some of the drawbacks that the researchers faced were the size, weight, and power consumption of reader systems that make them very difficult to embed in robots. Therefore, they set out to use ad hoc RFID hardware that was tailored for the desired application and demonstrated that customizing an RFID system for a desired application can improve overall performance (Catarinucci et al., 2013).

DiGiampaolo and Martinelli (2014) further explored the global localization of robots using RFID by using an autonomous vehicle equipped with odometry sensors to receive signals coming from passive RFID tags located in various locations on a ceiling. By using RFID tags located on the ceiling, DiGiampaolo and Martinelli (2014) were able to determine through experiments that

> a significant improvement is achieved with respect to other methods available in literature in terms of accuracy versus tag density; in particular, with respect to those methods, a lower steady-state error is obtained, and the time required to localize the robot is significantly shorter. (p. 376)

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IV. INDUSTRY’S APPLICATION OF TECHNOLOGIES FOR ASSET VISIBILITY AND DISTRIBUTION

A. KIVA SOLUTIONS

Kiva Systems was founded in 2003 by Mick Mountz who was looking at ways to reduce the cost of order fulfillment due to material handling. Kiva Systems was created to provide material handling solutions using “distributed intelligence” (Kiva, 2014) and automation that would increase speed, accuracy, and flexibility

The automated material handling system that Kiva created consists of robotic drive units (bots), mobile inventory shelves (pods), software, a wireless network and a server-based back end system. Although robots have been around a long time, what makes Kiva different is how they have “integrated three technologies: WiFi, digital camera, and low-cost servers capable of parallel processing” (Scanlon, 2009). When an order is received, using the automated system, a robot retrieves the merchandise that is stored in mobile inventory pods and brings it to a human operator. The merchandise is stored in pods in the center of the warehouse, where it waits until being shuttled, via a grid pattern of barcode stickers on the warehouse floor, to the perimeter where human operators stand at inventory stations putting orders together. By using robots, Kiva configured workstations that “support picking, replenishment, finishing, value-added services, quality control, and shipping” (Kiva, 2014). This eliminates the need for workers to walk around the warehouse, climbing ladders and looking for inventory and then bring the inventory to a station to prepare for shipment. Figure 5 is a depiction of the robotic drive and the mobile inventory shelf that the robot picks up that carries the merchandise to a picker.

Figure 5. Kiva Robotic Drive Unit and Mobile Inventory Shelf (from Kiva, 2014)

Each workstation can be equipped with unique equipment offering different capabilities based on the different shipment needs as well as workers' attributes. Classified and high value items could be directed to employees that are authorized to handle that type of material. Stations can be designed specifically for workers with disabilities and robots programmed to take specific items to those stations. By having robots perform these functions, companies can see their labor cost decrease while shortening the cycle-times from hours to minutes. Furthermore, "accuracy is achieved through the innovative station-based pick-to-light, put-to-light and scanning capabilities which are available for all items" (Kiva, 2014). This picking process offers many advantages to the company as well to the employees. The operators at these stations can provide quality control by scanning UPCs and performing a visual inspection. The program software can identify product changes and react quickly to demand changes, which can prompt the robots to store the faster moving products closer to the workers and relocate the slower moving items to a different storage location.

Once the orders are completed, they are stored on pods until the next truck is ready to be loaded. Figure 6 demonstrates the design of the inventory station where these operators pick, pack, and ship orders without having to retrieve any merchandise from the shelves.

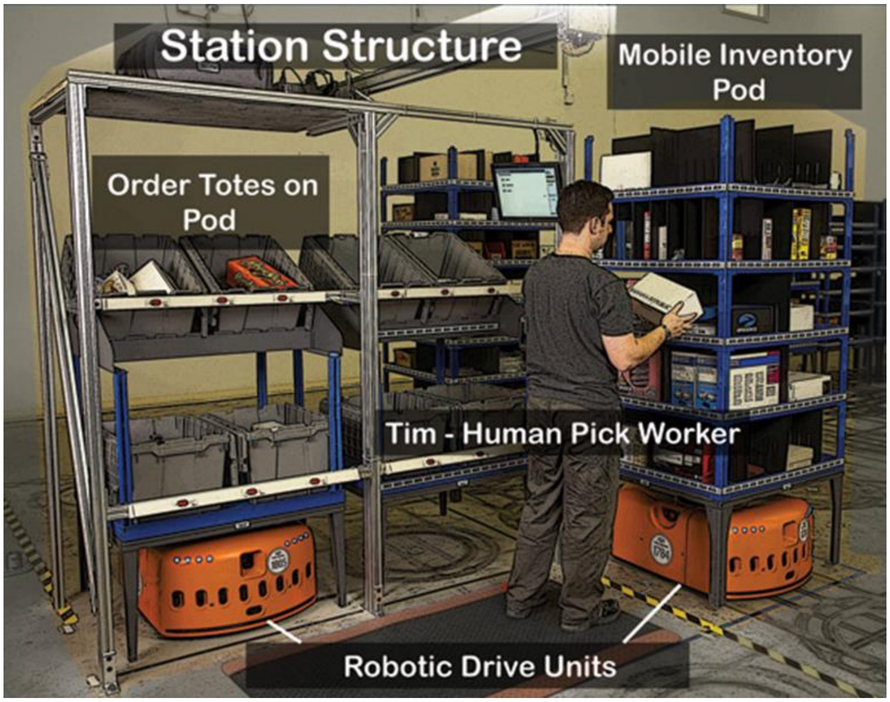

Figure 6. Kiva Work Station (from Kiva, 2014)

For customers who have multi-floors of inventory and use vertical space, Kiva Vertical Lift (KVLs) is a solution that can take a robot carrying a pallet of merchandise to various floors. Kiva boasts that their “KVLs operate much like other equipment lifts, but travel twice as fast as the industry average for industrial lifts” (Kiva, 2014). These KVLs have software that allow the drive units to access and operate the lifts. The drive units carry inventory to the lift and once situated on the lift, controls the lift to the floor needed. Once it reaches the desired floor, the drive unit steers it off the lift and stows it in its programmed location. Figure 7 is an example of the KVL.

Figure 7. Kiva Vertical Lift Solution (from Kiva, 2014)

To install Kiva Solutions, we must take into account the installation cost and operational costs. In order to install such a system, a company must take into account what its needs are and whether this requires new construction or adapting a preexisting building. Kiva works with its customer to specifically design a solution to meet the demands of the customer. Kiva boasts that since this is single automated system, they can easily design and install a solution and have it completed in a distribution center within weeks.

At the heart of Kiva warehouse automation is the configurable software that is used to piece the solution together and integrate it into an enterprise system. The software can be configured to an existing enterprise system and can adapt to the changing environment within the business when identifying more efficient practices. "During implementation, the Kiva software is integrated with the client's enterprise systems, including: warehouse management systems (WMS), order management systems (OMS), and enterprise resource planning systems (ERP)" (Kiva, 2014). Essentially, the software directs the robots to pick up a certain shelf that has a certain piece of inventory and tells the robot where to take it. Once the robot takes the shelf to a worker, the software identifies to the worker which part or piece of inventory is required from that shelf. It also has the capability to adapt to operation environment changes such as increases and decreases in inventory demands, alerting supervisors when trucks are late, re-routing time-sensitive orders to expedite the order, and even working around delays caused by missing inventory or retrieval problems. Figure 8 demonstrates the software integration in Kiva's warehouse automation solution.

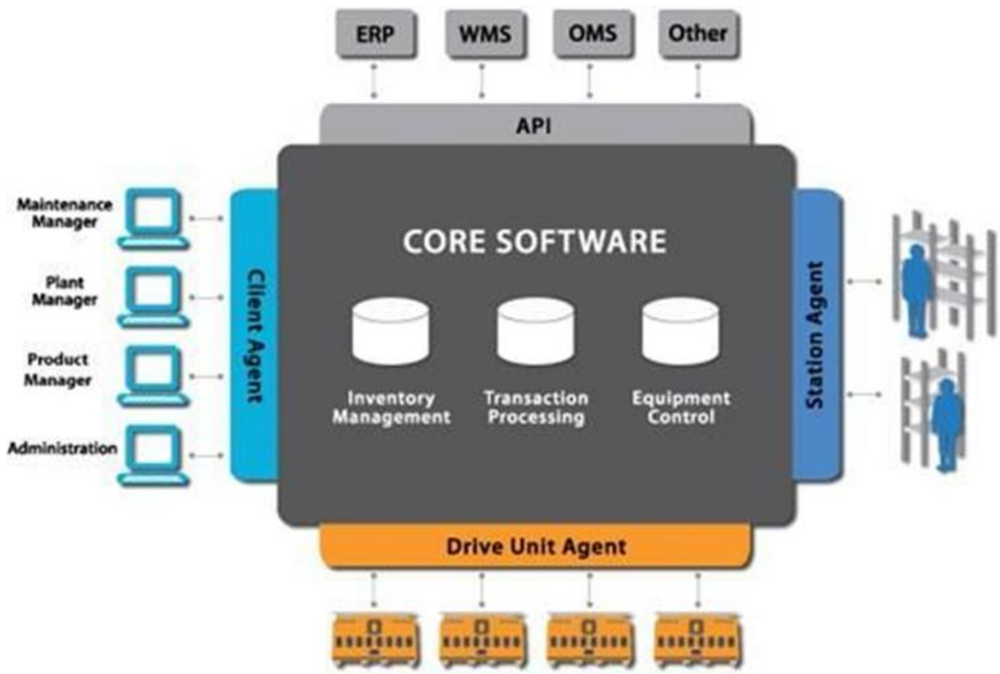

Figure 8. Kiva Software Integration Model (from Kiva, 2014)

Clients who are currently using Kiva boast that they have been able to achieve increased efficiencies, reduce cycle-time and lead-time, and provide 100% accuracy to customers for order fulfillments.

B. ZAPPOS

Zappos is an online shoe retailer that revolutionized the way consumers purchase shoes. In 2006, they bought a large fulfillment center in Shepherdsville, KY. The warehouse was state-of-the-art and had “static shelves, four stories high, 128 carousels, and 20,000 feet of conveyors” (Scanlon, 2009). The fulfillment center is 825,000 square feet that now has 23,000 feet of conveyors running 24 hours a day. At the time it was purchased, they were only able to utilize half of the space. In 2007, vice president of fulfillment at Zappos, Craig Adkins, described in a video made by The McGraw-Hill Company and posted on youtube.com the receipt, inventory management, and distribution of Zappos merchandise. At this time, Zappos had 11,000 brands in inventory offered on the website. There are 3.7 million units of inventory and over 90,000 SKUs stored in this warehouse. On average, Zappos sells around 27,000 units a day and during the Christmas season, they average 60,000 units per day. Based on the video, we describe the processes that Zappos uses to receive, stock, and distribute their merchandise.

When Zappos receives incoming merchandise, they immediately tag each item with its own specific barcode, which allows them to be able to store each piece of merchandise wherever there is space in the warehouse, instead of storing like items together in the same location. By assigning a unique barcode to each item, the item can be stored at any location, and its exact location is known when needed.

When merchandise arrives, it is put onto conveyors that extend into the trucks. From the trucks, they offload the master cases where they are conveyed to the receiving station to be received. All the conveyors have in-line barcode readers for reading the barcodes that are on the sides of all incoming boxes. As merchandise goes to the conveyors it decides where it needs to go and routes it accordingly. On any given day, they receive 20,000 to 30,000 units (pairs of shoes) but have the capacity to receive as many as 60,000.

There are 20 receiving stations that run all at one time. The receiver at the station will open the cases, pull out the items from the case, and scan the manufacturer’s UPC. The receiver then attaches an individual barcode that Zappos describe as a “license plate number” on each box of shoes, even if the shoes are identical, which is assigned its own unique serial number. “The license plate number allows the company to track who picked, received, bought and returned any particular item” (Zager, 2009). This is the point of receipt for the merchandise. The number is then entered into the inventory system and recorded as received. That way, Zappos can track that specific pair of shoes from the receiving point, throughout any location within the warehouse and its delivery, providing a history of the item. As for the automated technology Zappos uses, “nearly all of the company’s information technology is developed in-house—no off-the-shelf system would meet its unique needs—and its storage and shipping systems are linked through a central database to the e-commerce site” (Zager, 2009). Once the item is received, it is pushed off onto a takeaway belt that runs through the system and takes the item to the inventory system for storage.

In the center of the warehouse, Zappos has a merging system that they describe as a spider merge. This was designed and installed to speed up the conveyors. In their original design, conveyors traveled throughout the warehouse and continued to each level of the facility carrying merchandise until the merchandise reached the outbound location. This process resulted in a 35-minute travel time for a box on the conveyor. This is very typical of what most warehouses look like and the process that they follow. In order to decrease the travel time, merchandise from all floors comes together at the spider merge where it is then taken to an outbound location, cutting down the travel time of a box from 35 minutes to 5 minutes.

Everything in the warehouse is random access storage. Storing everything according to completely random access provides more accuracy from an inventory standpoint because the item is almost always where the computer says it is. Zappos boast that their accuracy is better than almost any other company out there. Over the last two years of auditing, there has never been an inventory discrepancy. Another advantage to this system is that if everything were stored together by type, color, size, and manufacturer, finding that merchandise is more prone to human error. The systems tell the picker where that item is located, and they use radio frequency (RF) scanners, eliminating the need for paper picking or picking the items from a list. The system identifies the items needed and then directs the picker to the location of the item. The item is then scanned with the RF scanner and placed on a takeaway conveyor. “In static storage, pickers walk 12 miles a day; in the carousel area, the items come to them and they can pick at about twice the speed” (Zager, 2009).

There is an average of 3.5 hours from the time a customer clicks the button to order until the time the order is placed on the truck. There is quite a bit of variation in the number of hours due to the business peak times and the different times of the day. Since most of the trucks are loaded at night, there are more employees working the later shifts rather than the morning and afternoon shifts.

Once the item gets to the packer, they scan the barcode on the item, which initiates the printing of a packing slip with a barcode, which will then be affixed to the outside of the shipping box. This becomes the order identification for that order. The order is then sealed and placed on a conveyor that will take it to the appropriate truck to be loaded.

C. ZAPPOS INTEGRATES KIVA SYSTEMS

In a video posted on *Wired*, Adkins described how Kiva changed the way they did business. In the later part of 2008, Zappos turned the unused part of their warehouse, approximately 416,000 square feet, into an automated operation that was run by robots from Kiva Solutions. It only took four months from the time the contract was executed until the time that Zappos was able to fulfill its first order. This is an extremely fast installation for a major warehouse. Now Zappos has approximately one-half of the warehouse using carousels, conveyors, and personnel picking items and the other half using robots from Kiva. From the time that Kiva robots were implemented, Adkins pointed out that inventory accuracy was consistently 100% and recorded no safety incidents whereas the older side usually had two to three incidents per week.

On the robotic side of the warehouse, “72 Kiva bots are in constant, quiet motion, carrying one of Zappos’ 3000 storage pods to or from” (Scanlon, 2009) delivery merchandise to people who will put together an order. When Zappos teamed up with Kiva, they collaborated to develop a solution to best meet their needs. For example, the modular design of the pod was designed in order to meet the storage designs of their different merchandise, such as golf bags, golf clubs, flat apparel, shoes, and jewelry. The robots allow them to process around 35,000 units a day, half of which are single orders and the other half is being multi orders. Kiva allowed them to find a solution to their sortation problems by taking the complexity out of sortation, which helped increase the amount of units processed. The defect rate, which is a process that does not perform within its specifications, in the Kiva side of the warehouse is 0%. The storage density on the Kiva side of the warehouse is 80% better than the storage utilization in the traditional side of the building.

Robots allow the workers to remain constantly on task increasing productivity by 50%. Robots provide a queue of work for workers that equates to "every six seconds, a worker takes an item from its pod and puts it into a shipping box, packing some 600 items an hour" (Scanlon, 2009). Workers are not just standing around waiting for something to happen; there is always something to do. Adkins pointed out that this has resulted in a 50% reduction in labor on the outbound side of the business. He also noted that they did not have to lay people off or eliminate their jobs, but that as the company grows, they will not have to hire as many employees.

Another benefit of Kiva is the training cycle-time. On the traditional side of the warehouse, it takes new employees about four days to learn their job before they can work on their own. With Kiva, it takes half a day to train an employee.

Since Zappos is a service-oriented company with the goal of getting an order to the customer as quickly as possible, Adkins pointed out that another significant benefit was that Kiva enabled Zappos to get an order out within 12 minutes instead of the original range of 48 minutes to 3 hours in the older part of the warehouse. In order to get the time down to 48 minutes in the traditional side of the warehouse, Zappos had to spend extra capital to get to 48 minutes by improving material handling beyond what is normally available off the shelf. Kiva allowed them to achieve 12 minutes without any extra expense.

Energy savings is another big benefit. Robots eliminated the need to provide light to their side of the warehouse. The only place that light is needed is in the area where the people are. Zappos does not need to provide air conditioning for the whole warehouse. In the article "Autonomous Robots Invade Retail Warehouses," Madrigal (2009) stated "That allows warehouse operators to switch off the lights and climate controls in the large areas of the warehouse that are patrolled solely by robots, cutting energy costs by as much as 50 percent over a standard warehouse." They need only to provide climate control to areas in which there are people working, whereas on the other side of the warehouse, they have to provide climate control for the entire 416,000 square foot space. This provides huge energy savings for this side of the warehouse. They have "cut in half its utility costs per square foot" (Scanlon, 2009). Additionally, the traditional side of the warehouse has 23,000 feet of conveyors running 24 hours a day, seven days a week, with 600 motors that are constantly running, whereas Kiva side of the warehouse does not have this operation.

Another advantage is that there is no pilferage of higher costing merchandise. There is natural security because everywhere pods and robots are located are personnel exclusion areas. Therefore, this provides a natural security meaning the only opportunity for shrinkage is as the order comes to the picker.

V. METHODOLOGY

A. PROBLEM EXPLORATION

During the exploration of this topic, a thorough investigation was completed examining the different applications in which robotics and RFID were currently being used in inventory functions as well as the importance of the following questions:

- Why use RFID?
- What happened after the huge initial boom in RFID technology, and how are companies implementing this technology?
- If robots can be used, what capacity should they serve?
- Would the benefits be worth the capital investment (costs)?

As a starting point, the project focused on RFID technology and its potential use when combined with robots to improve asset visibility in DLA warehouses. The DLA was looking for research to explore, discover, and evaluate the potential real world (DLA Distribution) applications of using robotics and RFID to perform inventory functions in DLA Warehouses.

The first step taken was an in-depth literature review not only on RFID and robotics, but the DOD policies that were driving implementation of these technologies. This was accomplished by using past theses, GAO case studies, manufacturers' websites, and various RFID and robotics books and journals.

After conducting the literature review, we realized that it would be hard to conceptualize the scope of the problem that the DLA needed answered without examining and experiencing the different processes that occur within a warehouse. Therefore, it was decided that a site visit to one of the DLA's fulfillment centers would be critical in order to gain an understanding of the complexity and scope of operations to which a RFID and/or robotic solution could potentially be applied.

B. WHY THE DLA EASTERN DISTRIBUTION CENTER

Initially, a representative from DLA Office of Operations Research and Resource Analysis (DORRA) had interest in conducting an analysis using the Small Arms Repair Facility at Anniston Army Depot. The choice of Anniston Army Depot was due to the DLA's challenges in maintaining controlled item asset visibility of small arms and their associated parts. After considering the limitations with RFID transmission and metals, it was concluded that this might not be the best base-case analysis to use for potential applications for this type of technology.

The next recommendation was for a site visit to DLA Distribution, Susquehanna, PA. This site is the eastern DLA Strategic Distribution Platform, hosting the largest distribution facility in the DOD, the Eastern Distribution Center (EDC), which is responsible for 80% of the distribution occurring in Susquehanna. The major functions of the EDC include receiving, storage, issue, packing, preservation and packing, surface and equipment maintenance, Automatic Weigh and Offer System (AWOS), and Airlines of Communications (ALOC). Many warehouses in Susquehanna would provide an opportunity to understand the inventory and distribution of multiple warehouses; however, due to time constraints and the sheer magnitude of the sites, the EDC was chosen. The EDC has 1.7 million square feet of floor space and is the size of 30 football fields under one roof. There are 122 truck doors for delivery and receipt of inventory. The warehouse has a transportation system that includes 5.3 miles of towline that pulls 1,120 carts delivering parts around the warehouse. They also have 4.5 miles of conveyors that can haul 26,000 totes. Both the conveyors and the carts run 24 hours a day, moving inventory through various sections of the distribution center with a sortation system with 368 chutes. The types of technology that are employed in the EDC include barcode technology, conveyance tracking, and material tracking and control (Freeman, 2014). The Susquehanna site provided an opportunity to better understand DLA distribution functions, provide access to various warehouses, and conceptualizes how RFID and robotics technology could be applied to inventory functions in a future DLA warehouse.

C. UNDERSTANDING THE PROBLEM

The site visit provided a better understanding of the different activities with a distribution site. Based on observations during the tour of the EDC, it was hypothesized that most problems with inventory control are due to inadequate processes and human error. The EDC was built in the 1980s and has had new technologies layered onto old technologies. A point brought up by our guide, LTC Freeman, when discussing multi-pack boxes, strengthened this argument:[1]

> As the smaller boxes come off a conveyor they scan it with an RF gun, and then load them in a multi-pack box, and move onto the next item. The RF gun takes a while to read that barcode and sometimes it doesn't get a good read, so you'll get a "beep," and the item is put in the box. Some individuals don't stop to read [showing the screen] and make sure they got a good scan, which means that a product is leaving our building that we didn't catch, leaving an active Material Release Order (MRO).[2]

In order to address the hypothesis and develop a solution, it was determined that there would be a need to expand the research on RFID to other forms of Auto-ID. Looking at only one form of technology without comparison would be insufficient. A thorough review was accomplished of the following current technologies: active RFID, passive RFID, standard barcodes, 2D barcodes, and material handling robotics. An examination of how companies were using that technology was completed in order to understand how these various technologies were improving operations.

To answer the immediate question of what automatic identification technology (AIT) would most benefit DLA asset visibility, the focus of our analysis was on 2D barcodes and passive RFID tags. A separate analysis was conducted on how robotics could also be used to improve inventory management and order processing in the future.

In order to develop a recommendation of which technologies would most improve asset visibility in a DLA distribution center, we further focused our analysis on four

[1] A multi-pack box is a large cardboard crate into which individually ordered items are consolidated for shipment to one geographic location.

[2] A Material Release Order is the actual order inventory, generated by the customer request, of items to be shipped.

factors: Technology Readiness Level (TRL), Reliability Comparison, and a cost–benefit analysis.

To conduct this cost analysis, DORRA provided inventory data on annual receipts of items, storage locations (bins, pallets, bulk), numbers of inventories conducted, and the manpower requirements in hours and salaries to conduct these inventories. Additional data were requested on MROs that were not filled and the total dollar value of the receipts at the EDC. Using this data, a net present value (NPV) analysis was conducted on the costs of systems for four different business cases: (1) RFID tagging of every item within the EDC, (2) RFID tagging for specific items/warehouse areas, (3) 2D barcoding of every item within the EDC, and (4) robotics for inventory management and order processing. The overarching goal of the NPV analysis was to capture the calculable costs and benefits and determine to what extent the DLA can apply RFID or 2D barcode technology to receive the best value. Without access to large quantities of data, it is difficult to calculate some tangible benefits, and it is even more difficult to assign a dollar value to some of the intangible benefits; therefore the NPVs are calculated to demonstrate what the value of these benefits need to be to break even.

D. WHAT ITEMS ARE CONSIDERED FOR TAGGING?

In order to simplify this study, only the current quantities of items within the EDC as well as the receipts of new inventory for the past three years were examined. There is an apparent downward trend in new inventory over the time period; however, the DLA expects this trend to level off between fiscal year (FY) 2014 and FY2015. For this study, we incorporated the results of Chonko et al. (2014) on projected workload for the DLA. They projected an overall decrease in workload of 8.68% across the DLA. This percentage reduction was applied to the August 2013–July 2014 numbers to establish the baseline, which is depicted in the following table.

Table 3. EDC Annual Inventory Induction, for fiscal years 2012, 2013, and 2014

Annual Inventory Induction	AUG 11 - JUL 12	AUG 12 - JUL 13	AUG 13-AUG14	Projected
Number of Items currently stored in the warehouse			342,390,713	312,667,775
DLA number of "lines"stored			781,171	713,358
Mean Number of "lines" of items received annually	786,052	662,208	527,637	481,833
Number of items receive annually	189,754,849	155,584,142	114,845,918	104,876,144

The type of storage for these items was examined in order to develop different courses of action. The locations referenced in Table 4 are physical storage locations, shelves, or floor spaces.

Table 4. Storage Locations by Type within the EDC

Storage Type	# of Locations
Bins (Individual "eaches", small items)	692,548
Bulk (Items shipped in quantity, eg. Barrels, chairs)	110,300
Rack (Individual, heavy items on pallets)	158,753
Total	**961,601**

The DLA conducts several forms of inventories depending on the requirement. These inventories represent a significant quantity of labor hours and require a substantial amount of full-time equivalent (FTE) labor. These inventories are shown in Table 5.

Table 5. Average Annual Inventory Requirements within the EDC

Inventories	Minutes take each Occurrence	Mean Annual Occurrences (Workload)	Mean Annual Hours	Mean Work hours per worker	FTE (workers) DLA
Causative Research Inventory	80.6	7032	9446.32	1534.99	6.15
1st Count	5.19	27057	2340.43	1341.22	1.75
2nd Count	5.19	27057	2340.43	1341.22	1.75
3rd Count	30.59	29544	15062.52	1533.60	9.82
Location survey	0.5	445392	3711.60	1534.99	2.42
Location Survey Batch	10.64	6000	1064.00	1534.91	0.69

E. ASSIGNING COST OF LABOR

To determine the annual costs of labor to perform inventories at the EDC, the average salary for the employees performing the inventories needed to be calculated. The pay grades for the employees conducting inventories was given by the DLA, GS 7-step 9 to GS 9-step 9.[3] Also factored in was the locality pay for Susquehanna, which adds an additional 24.22% to their annual pay. This is shown in Table 6.

Table 6. Average Annual Salary for FTEs Conducting Inventories

GS 7-Step 9	GS 8-Step 9	GS 9-Step 9	Average Pay
$ 43,471.00	$ 48,143.00	$ 53,171.00	$ 48,261.67
		locality pay 24.22%	$ 11,688.98
		Total Avg Salary	**$ 59,950.64**

The calculation of hourly wage rates for personnel receiving inventory (customers) was also calculated. Based on our personal experience, the number of sailors by pay grade in a supply support and the number of soldiers in a maintenance parts shop by pay grade was used for as an estimated sample. Using the FY2014 pay scale from the Defense Finance and Accounting Service, a weighted-average monthly salary was developed. The average hourly wage rate was then calculated based on a standard 168-hour work month.

[3] This number is only an estimate. The number of employees at each pay grade was unavailable for a weighted average. The actual annual salary could be slightly higher or lower.

Table 7. Calculation of Hourly Wage Rate for Enlisted Personnel

	Qty Personnel	Mo. Salary	Weighted Salary
E5 (over 6yr)	6	2734.5	16407
E4 (over 4yr)	7	2328	16296
E3 (over 2yr)	9	1918.8	17269.2
		Total Avg Salary	2271.46
Full work month	168 hours	Hourly Wage Rate	$ 13.52

F. INFRASTRUCTURE COST BASELINE

To establish and estimate the costs for infrastructure, we used Bhuptani and Moradpour's criteria outlined in *The RFID Guide: Deploying Radio Frequency Identification Systems* as a guideline to determine the categories of costs. Bhuptani and Moradpour (2005) described the categories for cost based analysis as

- RFID readers
- RFID antennas
- Printer costs
- Tag costs (includes both the tag and ink)
- Software/computer/middlewear costs
- Installation/set-up and tuning
- Annual maintenance and support costs
- Integration and business process reengineering (pp. 118)

The dollar value of the equipment listed in this book was determined to no longer be valid due to the 2005 publication date since the value of the dollar has changed and technology has advanced. To estimate the average per tag cost for RFID and 2D barcodes, research was conducted through multiple equipment retailers for printers, tags, and ink. After reviewing output capability of multiple brands, Zebra, a well-known manufacturer, was determined to be a good basis for the cost analysis. Utilizing only one manufacturer made it easier to directly compare prices. This manufacturer is meant to be used only as an example, not as a manufacturer that is superior or inferior to any other. The prices used were the lowest found and are strictly an estimate. Prices for the two passive RFID tags were obtained from an article by Watson (2013) on the AMI Tracks website. Economies of scale may potentially be recognized; however, they are not used in this analysis.

Table 8. RFID/Barcode Tags and Printer Costs

RFID Printers	
Zebra® ZT410™ RFID Printer/Encoder (203 DPI, UHF)	$3,665.00
Standard Passive RFID Tag Price	$0.10
Metal Mountable Passive RFID Tag Price	$1.50
Barcode Printers	
Zebra ZM400 Thermal Barcode Printer (203DPI)	$1,388.60
1x Roll Barcode Labels (Zebra) @ 2,750 tags per role (2"x4")	$74 = $0.027 per tag
1 x Role Zebra_555 Standard Resin Ribbon (4250 Label equivelent)	$32 = $.0076 per tag
Total Price Per Tag	$.04 (rounded-up)

Based on categories of cost identified by Bhuptani and Moradpour (2005), we researched and identified updated pricing. These updated prices are as follows:

- Fixed readers: Prices for fixed readers range between $10,000 and $20,000 (Watson, 2013). For the analysis, the median price of $15,000 per fixed reader was used in the calculation.

- Handheld readers: The estimated cost is $3,000 per reader (Watson, 2013).

- Software/middleware: The cost of middleware for a $12 billion volume manufacturer looking to meet RFID tagging requirements of a major retailer is $183,000 (Violino, 2005).

- Integration, consulting, testing and setup: For a $12 billion volume manufacturer the cost is $128,000 for consulting and integration, $315,000 for the time of the internal project team and $80,000 for tag and reader testing. The total cost is estimated to be $523,000 (Violino, 2005).

- Annual software maintenance: a typical benchmark for software maintenance is 20% of acquisition costs per year (Computer Economics, 2005). The estimated annual cost is $36,600.

For the 2D barcode system, we used the same system setup cost, minus the tag and reader testing. We also did not factor a cost of fixed readers, as we assumed the current fixed reader infrastructure within the EDC will not change. However, we assume that there would be a requirement for new handheld 2D barcode Readers. For our analysis, we used the Motorola DS6878-DL cordless 2D scanner as it is currently an industry best seller and the specifications would meet the requirement. The price for this scanner is $695.70.

G. COST ASSUMPTIONS

1. 150 fixed RFID readers are sufficient to cover the EDC and would require replacement due to wear and advances in technology every five years.

2. 100 handheld RFID readers are sufficient for the EDC for active use and spares and would require replacement every two years due to breakage and technology advancement.

3. 100 handheld 2D barcode scanners are sufficient for the EDC for active use and spares and would require replacement every two years due to breakage and technology advancement.

4. A printer will be required for each induction station (29) as well as a bench stock (20%) to maintain 100% utilization time for each induction point, for a total of 35 printers.

5. Costs for software/middleware, integration, and consulting will be the same for the EDC as for a Manufacturing company with $12 billion in volume.

6. The DLA can expect to pay (20%) of the total software cost annually for software maintenance.

7. The DLA already has an adequate number of fixed barcode readers to meet the current process requirements.

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VI. ANALYSIS

In determining the cost analysis, several different factors were considered. An assessment was completed on the TRL of both passive RFID and 2D barcoding based on literature and current practices. Then an examination into various technologies exhibits a higher level of reliability for different applications. Finally, the data demonstrate several potential applications for each technology when combining these factors with a cost–benefit analysis.

A. ASSESSING TECHNOLOGY READINESS LEVELS

In *The Department of Defense Guide Technology Readiness Level: Technology Readiness Assessment Guidance*, definitions are provided that assisted that helped us assess the technology readiness level. Using these definitions, it is obvious that both passive RFID and 2D barcodes are already at a TRL 9.[4] Both technologies are currently employed across a broad spectrum of operations. This spectrum includes shipping and receiving to inventory control in the retail business. It was decided that the focus of should be on whether the technology is suitable and mature enough for application to DLA distribution.

Passive RFID technology excels in use for asset visibility for textiles, paper goods, perishable goods, and medical supplies. The effectiveness of passive RFID is limited by interference from other passive RFID tags, metals, and liquids. There has been an increased effort to make passive tags less susceptible to interference, make them work on metal, and increase their read range through expanding the transmission spectrum into UHF, passive RFID. This technology, however, has still not overcome its limitations when it comes to these weaknesses. Within the EDC, the DLA stores large volumes of items in close proximity with a vast quantity of items made of metal. It is recommended that any implementation be carried out via a pilot or trial installation first to measure the performance of the system. Due to this requirement, we evaluate passive RFID for EDC

[4] See the appendix: Technology Readiness Levels

usage at a TRL of 6 for any of the business cases considered as the system has not yet been demonstrated in this operational environment.

B. RELIABILITY COMPARISON

In Chapter III, general challenges with passive RFID and 2D barcodes were explored. To compare reliability of the two technologies, reliability issues that could occur within the EDC were considered.

Table 9. Reliability Comparison (after White et al., 2007)

2D BARCODES	PASSIVE RFID TAGS
No power source required	No power source required
2D Barcodes can be read even when damaged	Can cope with harsh or dirty environments
Visual scan, items not in line-of-sight aren't read by the reader	Reader must be aimed at the tag
Can be printed on durable materials not affected by substrate materials or electromagnetic emissions	Two RFIDs transmitting in close proximity may interfere with each other (difficulty with stacked items)
	Does not transmit well through liquids and metals
	Other commonly used transmitting technologies can cause interference

In a case study conducted by researchers from the University of West England, White et al. (2007) conducted an analysis to directly compare RFID and 1D barcodes. Emphasis was placed on scanning cycle-time and equipment breakdowns. The data were collected by "conducting time and motion studies of operators using both RIFD and barcode technology to scan products delivered in stackable plastic trays" (White et al., 2007).

White et al. (2007) determined that scanning items with RFID is faster than scanning barcodes. Note, however, one of the leading causes of the increased scan time of barcodes was due to damaged labels. 2D barcodes are still able to be read when damaged.

Table 10. RFID Errors in Scanning (from White et al., 2007)

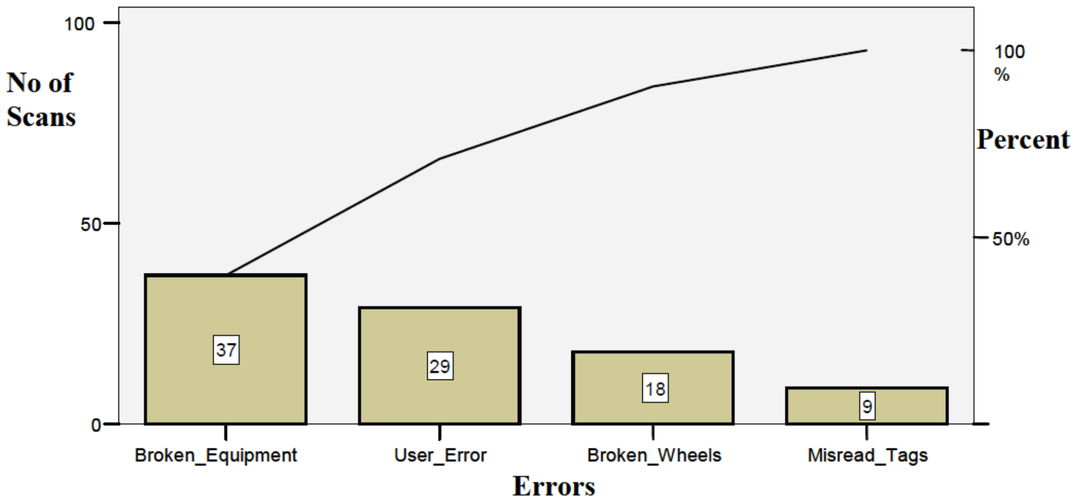
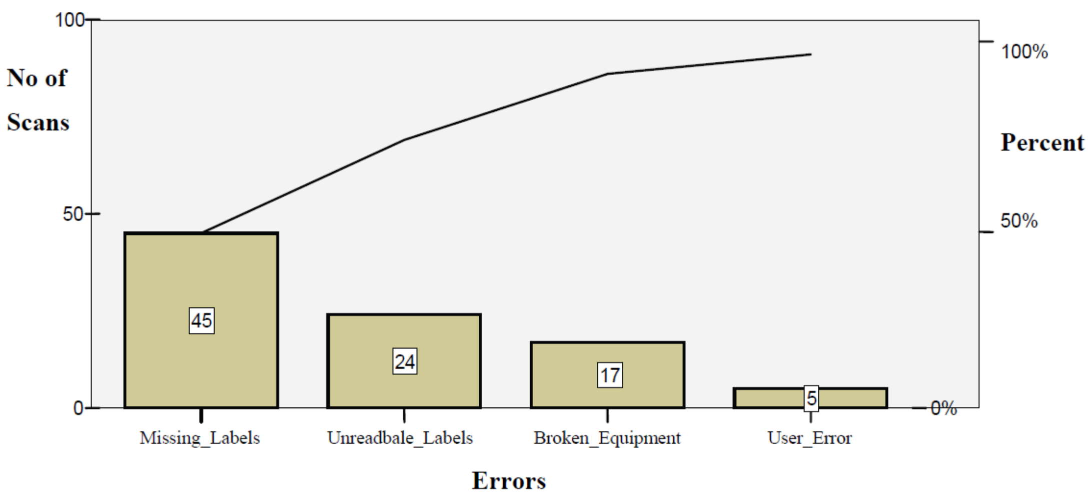


Table 11. Barcode Errors in Scanning (from White et al., 2007)



By analyzing the leading causes of read failures for RFID, it was discovered that read failures were usually due to equipment failure or user error. In the barcode test, missing or damaged labels were the leading cause of failure. Since 2D barcode can still be read, when this leading cause of failure in barcodes is subtracted from the above analysis, the percentage of failure in barcodes is reduced.

C. COST–BENEFIT ANALYSIS

The cost–benefit analysis was conducted in three steps. For each case we identified costs related to the overall system and the tags. We then considered the tangible and intangible benefits, applying a dollar value in areas where data allowed an assumption. With these numbers, we then conducted a Net Present Value (NPV) assessment over a 10-year period. As there are several benefits that are not captured in the NPV analysis, we use the results to determine a breakeven value. These benefits are outlined in section 2.c.

1. Assigning Costs

a. Business Case #1: Full RFID Implementation

(1) System and Equipment Costs

To determine costs associated with RFID application, we developed an estimate of the system acquisition and implementation costs using the data from our different sources. These items are identified in Table 12.

Table 12. Estimated RFID System Acquisition Costs

Item	Qty Req	UI	Unit Cost	Total Cost
Fixed Readers	150	Each	$15,000	$2,250,000
Handheld Readers	100	Each	$3,000	$300,000
Printers	35	each	$3,665	$128,275
Software/Middleware	1	license	183000	$183,000
Integration and Consulting	1	implementation	$128,000	$128,000
Internal Project Team	1	team	$315,000	$315,000
Tag and reader testing	1	test	$80,000	$80,000
Software Maintenance	1	Annual	$36,000	$36,000
Total System Acquistion Cost				**$3,420,275**

Our assumptions are that printers will require replacement every two years due to normal wear and tear, fixed readers will require replacement every five years due to both equipment life cycle and technological advances, and handheld readers will require replacement, on average, every three years due to wear-out, breakage, and new technology. We also assume that the replacement costs for these items will decrease at a rate of at least 1% per year, with inflation taken into account, due to innovations in technology.

(2) Tagging Cost

In order for the new system to be effective, our assumption is that all items in the warehouse must be tagged as part of the implementation. If all items are not tagged, the EDC may never receive the full return on investment as physical inventories will need to occur for the untagged items. This upfront cost will be very high due to both the quantity of tags and the labor hours required to tag every item. Using an estimate provided by Lahiri (2006), we calculated the time it takes to tag an item is 30 seconds. Our estimated number of items in inventory for the next fiscal year is 312 million. Assuming item turnover is approximately the same as our estimated new inventory receipts of 104 million items, we estimate only 208 million items will require separate tagging at implementation. Using the data in Tables 5 and 6 to calculate the average hourly salary, it will cost approximately $67 million in labor to tag all items. This data is shown in Table 13.

Table 13. Estimated Labor Costs of Implementation

# Items	Minutes/tag	Total Hours	Wage/hr	Total Labor Costs
208,000,000	0.5	1,733,333.33	$ 39.06	$67,704,000

To determine the initial tagging cost, the average cost per tag had to be calculated. Since the composition of each item in the EDC is unknown, we assumed that 90% of the items would be non-metallic. We base this assumption on our direct observations that most items are either in nonmetallic packaging or are mounted on pallets during storage and shipping. A pallet can be tagged to avoid the interference caused by mounting passive RFID tags on metal surfaces, thus reducing the requirement for specialized tags.

We calculated the average implementation cost of tags using a 90/10 ratio (normal/metal tags) for a total value of $49,920,000. We conducted a sensitivity analysis of different ratios of tags, which is shown in Table 14.

Table 14. Sensitivity Analysis of Initial RFID Tag Cost

		Total Items to tag	208,000,000			
		% composition of items tagged				
Tag Type	**Avg Cost/tag**	**10/90**	**25/75**	**50/50**	**75/25**	**90/10**
Normal Item	$0.10	$2,080,000	$5,200,000	$10,400,000	$15,600,000	$18,720,000
Metal Item	$1.50	$280,800,000	$234,000,000	$156,000,000	$78,000,000	$31,200,000
	Total Cost	$282,880,000	$239,200,000	$166,400,000	$93,600,000	$49,920,000

During implementation, the total estimated cost generated for tags and labor to tag each item is $117,624,000.

To determine the annual cost of tagging, we use our estimated new inventory receipts. At the induction point, we did not calculate the 30 seconds to tag items as an additional labor cost. During our site visit, we observed inefficiencies at the induction points. At one induction point, we witnessed personnel experiencing difficulties navigating between the internal DLA network and Wide Area Work Flow (WAWF). While observing, the employee was kicked out of the system twice. Our assumption is that improved efficiency during induction will offset the additional time requirement for tagging.

For the quantity of items requiring tags, we used our established baseline of 104,876,144. This number is used in the NPV for all 10 years.

Using the same composition metric for tag type, we calculated the average annual cost of tags using a 90/10 ratio (normal/metal tags) for a total value of $25,170,274.56. We conducted a sensitivity analysis of different ratios of tags, which is shown in Table 15.

Table 15. Sensitivity Analysis of Annual Passive RFID Costs

		TOTAL ITEMS TO BE TAGGED:		104,876,144.00		
		% of composition of items tagged (Non Metal vs Metal)				
Tag Type	**Avg Cost/tag**	**10/90**	**25/75**	**50/50**	**75/25**	**90/10**
Normal Item	$0.10	$1,048,761.44	$2,621,903.60	$5,243,807.20	$7,865,710.80	$9,438,852.96
Metal Item	$1.50	$141,582,794.40	$117,985,662.00	$78,657,108.00	$39,328,554.00	$15,731,421.60
	Total Cost	$142,631,555.84	$120,607,565.60	$83,900,915.20	$47,194,264.80	$25,170,274.56

b. Business Case #2: Full 2D Barcode Implementation

(1) System Costs

The costs of implementing a 2D barcode system are substantially less. Our assumption is that much of the barcode system that is currently in place within the EDC can continue to be used for this case. Our estimate of the system acquisition costs for 2D barcodes is represented in the following table.

Table 16. Estimated 2D Barcode System Acquisition Costs

Item	Qty Req	UI	Unit Cost	Total Cost
Cordless BC Readers	100	each	$695.70	$69,570.00
Printers	35	Each	$1,338.60	$46,851.00
Software/Middleware	1	license	$183,000	$183,000
Integration and Consulti	1	implementation	$128,000	$128,000
Internal Project Team	1	team	$31,500	$31,500
Software Maintenance	1	Annual	$36,000	$36,000
	Total System Acquistion Cost			$494,921.00

Similar to the RFID system costs, we assume that on average, printers will require replacement every two years due to normal wear and tear, and handheld readers will require replacement every three years due to wear-out, breakage, and new technology. Due to innovations in technology, with inflation taken into account, we assume that the replacement costs for these items will decrease at a rate of at least 1% per year.

(2) Tagging Costs

Utilizing the same numbers as the #1 RFID case, 208,000,000 for implementation and 104,876,144 for annual, we determined the implementation tagging cost and the annual tagging cost. Although we utilized the same base, 2D barcodes are significantly cheaper. With a cost of $0.04 per printed tag, the implementation cost estimate for tagging, including labor, is $67,074,000, shown in Table 17, and the annual tagging cost for new inventory is $4,195,045.

Table 17. Tagging Costs at Implementation

# Items	Minutes/tag	Total Hours	Wage/hr	Total Labor Costs
208,000,000	0.5	1,733,333.33	$ 39.06	$67,704,000
		Tags	**Price per tag**	**Total Initial Tag Cost**
		208,000,000	0.04	8,320,000
				Total Initial Cost **$76,024,000**

c. Business Case #3: RFID Implementation for Highly Active Bulk and Rack Storage

(1) System Costs

For this case, only palletized items and items stored in bulk or rack storage will be tagged. The system implementation costs are slightly lower than the full RFID implementation case due to a decrease in the number of fixed readers, handheld readers, and RFID printers required. Our assumption ius that the number of required readers can be reduced by a third and printers by more than half. Printers will only be required at the bulk and rack induction points.

Table 18. System Implementation Costs: Rack and Bulk Storage

Item	Qty Req	UI	Unit Cost	Total Cost
Fixed Readers	100	Each	$15,000	$1,500,000
Handheld Readers	65	Each	$3,000	$195,000
Printers	15	each	$3,665	$54,975
Software/Middleware	1	license	183000	$183,000
Integration and Consulting	1	plementat	$128,000	$128,000
Internal Project Team	1	team	$31,500	$31,500
Tag and reader testing	1	test	$80,000	$80,000
Software Maintenance	1	Annual	$36,000	$36,000
		Total System Acquistion Cost		**$2,208,475**

Rack and bulk storage comprise a much lower number of items than either Case #1 or #2 which will result in a much lower implemenation and annual tag cost. The following table shows the number of items in rack and bulk storage.

Table 19. Items by Storage Location Type

Locations	AUG 11 - JUL 12	Items Received by Location	AUG 12 - JUL 13	Items Received by Location	AUG 13-AUG14	Items Received by Location
Bins	57%	108,160,264	55%	85,571,278	34%	39,047,612
Bulk	18%	34,155,873	18%	28,005,146	27%	31,008,398
Rack	25%	47,438,712	27%	42,007,718	39%	44,789,908
Total		189754849		155584142		114845918
					Total Tags	75,798,306

To determine the cost of tags, we used the 90%/10% tag distribution, for both implementation and annual tagging costs and conducted a sensitivity analysis for different ratios of tag types shown in Tables 20 and 21. The maximum number of rack and bulk storage locations is 269,053, which is depicted in Table 4. This is the number used for calculating tags required for implementation. The total induction of an approximate 75 million items through the year makes it apparent that these areas experience a very high turnover rate.

Table 20. Sensitivity Analysis of Implementation Passive RFID Costs (Partial)

		Total Items to tag	269,053.00			
			% composition of items tagged			
Tag Type	**Avg Cost/tag**	**10/90**	**25/75**	**50/50**	**75/25**	**90/10**
Normal Item	$0.10	$2,691	$6,726	$13,453	$20,179	$24,215
Metal Item	$1.50	$363,222	$302,685	$201,790	$100,895	$40,358
	Total Cost	$365,912	$309,411	$215,242	$121,074	**$64,573**

Table 21. Sensitivity Analysis of Annual Passive RFID Costs (Partial)

		Total Items to tag	75,798,306			
			% of composition of items tagged (Non Metal vs Metal)			
Tag Type	**Avg Cost/tag**	**10/90**	**25/75**	**50/50**	**75/25**	**90/10**
Normal Item	$ 0.10	$ 757,983	$ 1,894,958	$ 3,789,915	$ 5,684,873	$ 6,821,848
Metal Item	$ 1.50	$ 102,327,713	$ 85,273,094	$ 56,848,729	$ 28,424,365	$ 11,369,746
	Total Cost	$ 103,085,696	$ 87,168,052	$ 60,638,645	$ 34,109,238	$ 18,191,593

2. Determine Benefits

a. Business Case #1 and #2: Full RFID or Full 2D Barcode Implementation

In determining benefits, the first step was to determine the average annual costs of conducting inventories. Using the data provided by DORRA for the EDC on the number of inventories by type, their mean occurrences, and the FTEs required to complete those inventories, we multiplied the Average Annual Wage for an FTE by DORRA's estimated quantity required. This provided the average annual costs to conduct each type of by-line-item inventory. The sum of these costs provided the average annual labor hour costs for conducting inventory audits. These costs are depicted in Table 22

Table 22. Total Annual Inventory Costs (Normal Operations)

Inventories	Minutes take each Occurrence	Mean Annual Occurrences (Workload)	Mean Annual Hours	Mean Work hours per worker	FTE (workers) DLA	Average Salary w/ Locality	Total Cost
Causative Research Inventory	80.6	7032	9446.32	1534.99	6.15	$ 59,951	$ 368,936
1st Count	5.19	27057	2340.43	1341.22	1.75	$ 59,951	$ 104,614
2nd Count	5.19	27057	2340.43	1341.22	1.75	$ 59,951	$ 104,614
3rd Count	30.59	29544	15062.52	1533.60	9.82	$ 59,951	$ 588,817
Location survey	0.5	445392	3711.60	1534.99	2.42	$ 59,951	$ 144,961
Location Survey Batch	10.64	6000	1064.00	1534.91	0.69	$ 59,951	$ 41,558
						Total Cost	**$ 1,353,500**

For our analysis, we assumed that by implementing Auto-ID, inventory auditing requirements would reduce significantly. No system is 100% effective; therefore there is still potential for misplaced inventory caused by human error and equipment failure. A tag can fall off, and a barcode or RFID tag can fail to function. We assumed that inventory auditing requirements can be reduced by a range of 75% to 95% with either of the two auto-ID technologies. This savings is recognized as a benefit in our analysis and is depicted in Table 23.

Table 23. Potential Savings in Inventory Auditing Costs

	Reduction		
	75%	85%	95%
Savings	$1,015,124.74	$1,150,474.71	$1,285,824.67

The second expected benefit is a reduction in unfilled MROs. Our assumption is that MROs are unfilled due to misplaced/untracked inventory. To calculate the average number of unfilled MROs we used the numbers provided by DLA Distribution Headquarters for the past three years, shown in Table 22. The denial rates are specifically for items that are listed as being on hand but when picked, cannot be located.

Table 24. Unfilled MROs

	MRO Denial Rates				Total MROs			
	FY 2011	FY 2012	FY 2013	FY 2014	FY 2011	FY 2012	FY 2013	FY 2014
Oct	0.68%	0.69%	0.51%	0.56%	473,261	380,998	355,742	240,607
Nov	0.50%	0.64%	0.62%	0.37%	425,192	375,595	364,133	289,584
Dec	0.54%	0.58%	0.58%	0.35%	462,054	395,816	346,721	280,146
Jan	0.62%	0.43%	0.49%	0.38%	497,306	384,768	342,365	278,534
Feb	0.56%	0.43%	0.46%	0.33%	454,085	398,228	339,392	309,146
Mar	0.49%	0.44%	0.42%	0.37%	572,948	460,583	351,280	336,728
Apr	0.50%	0.44%	0.43%	0.38%	545,995	398,350	325,868	357,865
May	0.53%	0.43%	0.51%	0.32%	521,782	381,563	359,719	368,995
Jun	0.59%	0.46%	0.41%	0.30%	555,557	431,795	347,150	321,368
Jul	0.69%	0.47%	0.39%	0.34%	500,028	396,038	288,065	329,047
Aug	0.69%	0.47%	0.43%	0.40%	536,707	442,125	403,252	352,534
Sep	0.67%	0.42%	0.44%	0.43%	488,240	432,197	373,996	330,901
Annual	**0.59%**	**0.49%**	**0.48%**	**0.37%**	**6,033,282**	**4,878,102**	**4,197,874**	**3,795,318**

	FY 2011	FY 2012	FY 2013	FY 2014
Unfilled	35,596	23,903	20,150	14,043

We then performed a Monte Carlo simulation on the data we had for the number of unfilled MROs over the last four fiscal years. Based on the Monte Carlo simulation, we estimated that the mean number of unfilled MROs over the last four fiscal years was 1,942. Over the last couple of years, as operational requirements have decreased, the amount of demand from the DLA has decreased. As demand decreases for the DLA, we estimate the mean number of unfilled MROs for the last fiscal year to be 1,178. We believe that this will likely be the average for the next couple of years if overall demand, processes, and procedures stay the same. The distribution in Figure 9 demonstrates, with a 95% probability interval, the expected number of MROs will fall between 527 and 3,354 per month. Based on our simulation run with the last four fiscal years of data, we estimate that there is only a 5% chance the number of unfilled MROs will be less than the lower confidence level (LCL) of 1,927, and only a 5% chance the number of unfilled MROs will be more than the upper confidence level (UCL) of 1,947. Assuming the sampling distribution of the number of unfilled MROs is distributed according to a normal distribution, a 95% confidence interval around the mean of 1,942 is 1,927(UCL)and 1,947 (LCL).

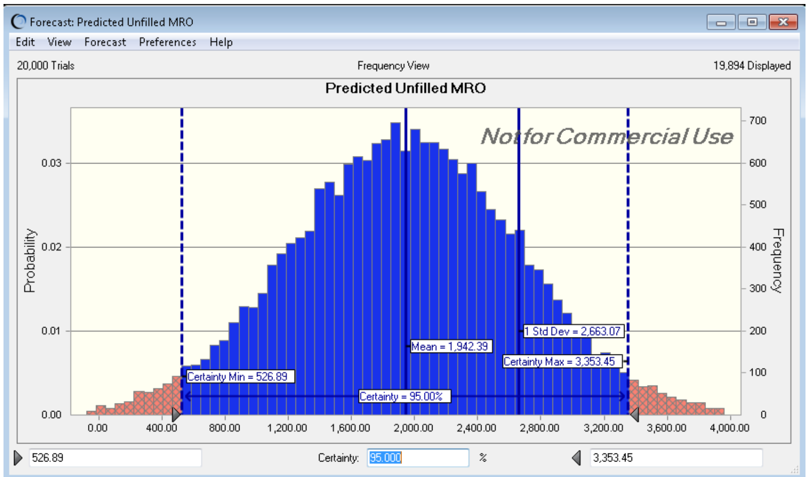
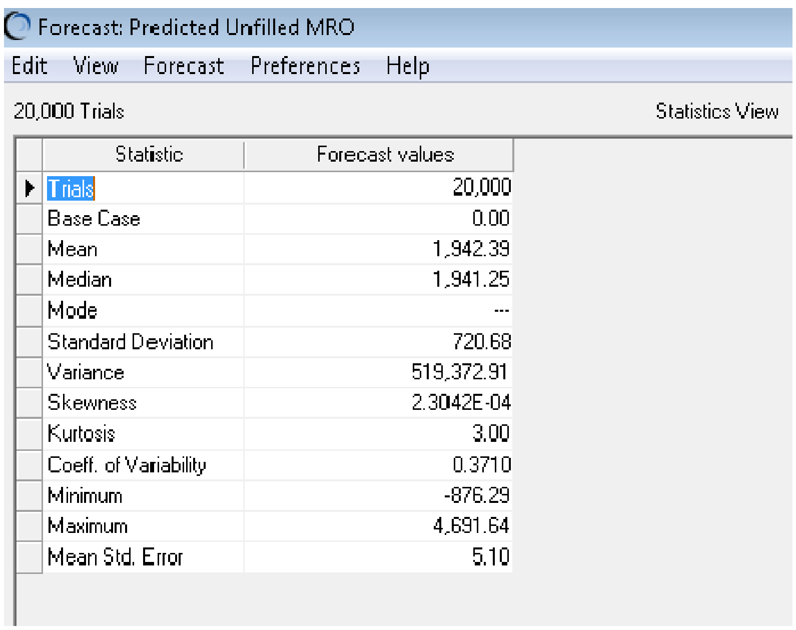


Figure 9. Predicted Unfilled MRO for FY2011–FY2014



Statistic	Forecast values
Trials	20,000
Base Case	0.00
Mean	1,942.39
Median	1,941.25
Mode	---
Standard Deviation	720.68
Variance	519,372.91
Skewness	2.3042E-04
Kurtosis	3.00
Coeff. of Variability	0.3710
Minimum	-876.29
Maximum	4,691.64
Mean Std. Error	5.10

Figure 10. Statistics of Predicted Unfilled MRO for FY2011–FY2014

In Figure 11, we determine that in the unlikely event that the expected number of unfilled MROs is less than our probability interval, on average the expected number is 259 unfilled MROs. This becomes a worst case scenario for cost savings represented by avoided unfilled MROs.

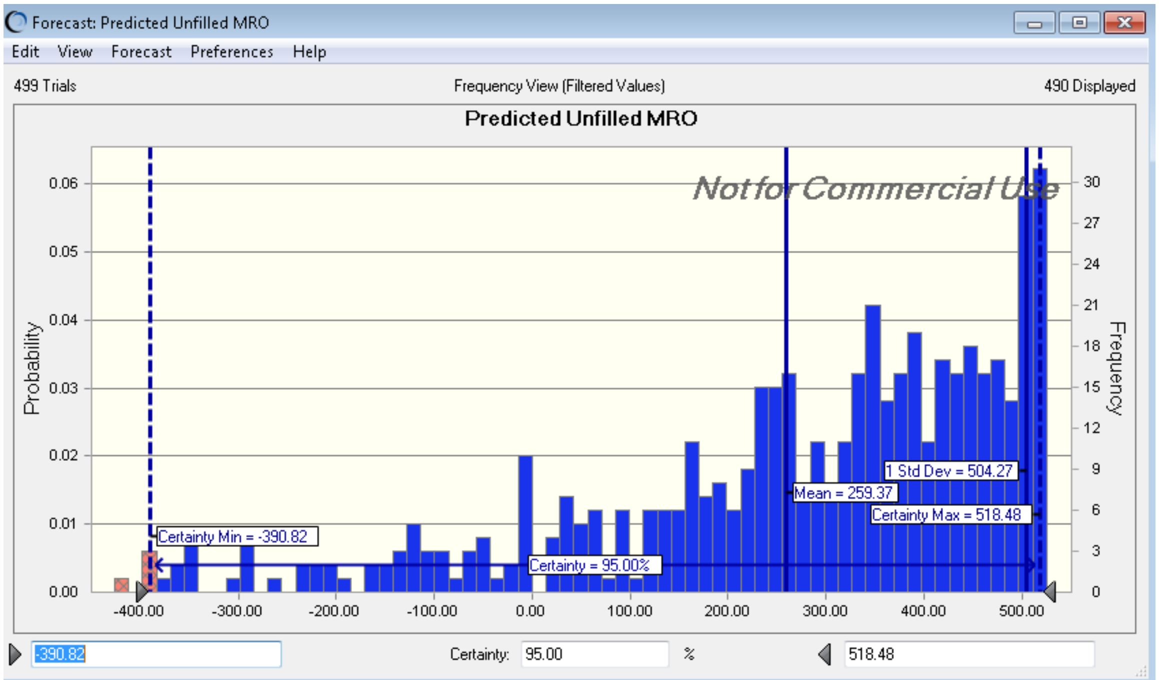


Figure 11. Left Tail of the Predicted Unfilled MRO for FY2011–FY2014

Based on our simulation run of the last fiscal year only, we estimate there is only a 5% chance that the number of unfilled MROs will be less than 1,174, and only a 5% chance that the number of unfilled MROs will be more than 1,180. Assuming the sampling distribution of the number of unfilled MROs is distributed according to a normal distribution, a 95% confidence interval around the mean of 1,178 is 1,174 (LCL) and 1,180 (UCL).

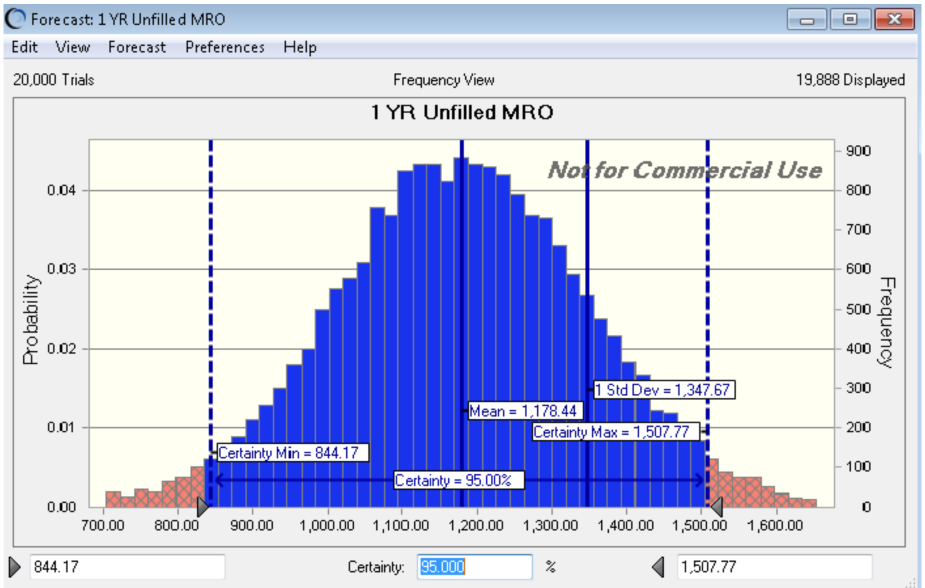
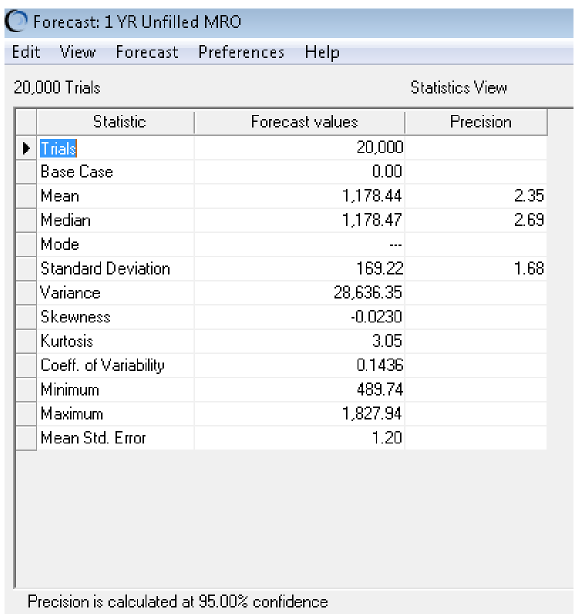


Figure 12. Predicted Unfilled MRO for FY2013


Forecast: 1 YR Unfilled MRO

Edit View Forecast Preferences Help

20,000 Trials Statistics View

Statistic	Forecast values	Precision
Trials	20,000	
Base Case	0.00	
Mean	1,178.44	2.35
Median	1,178.47	2.69
Mode	---	
Standard Deviation	169.22	1.68
Variance	28,636.35	
Skewness	-0.0230	
Kurtosis	3.05	
Coeff. of Variability	0.1436	
Minimum	489.74	
Maximum	1,827.94	
Mean Std. Error	1.20	

Precision is calculated at 95.00% confidence

Figure 13. Statistics for the Predicted Unfilled MRO for FY2013

In Figure 14, we determine that in the unlikely event that the expected number of unfilled MROs is less than our probability interval, on average the expected number is 775 unfilled MROs. This becomes a worst case scenario for cost savings represented by avoided unfilled MROs.

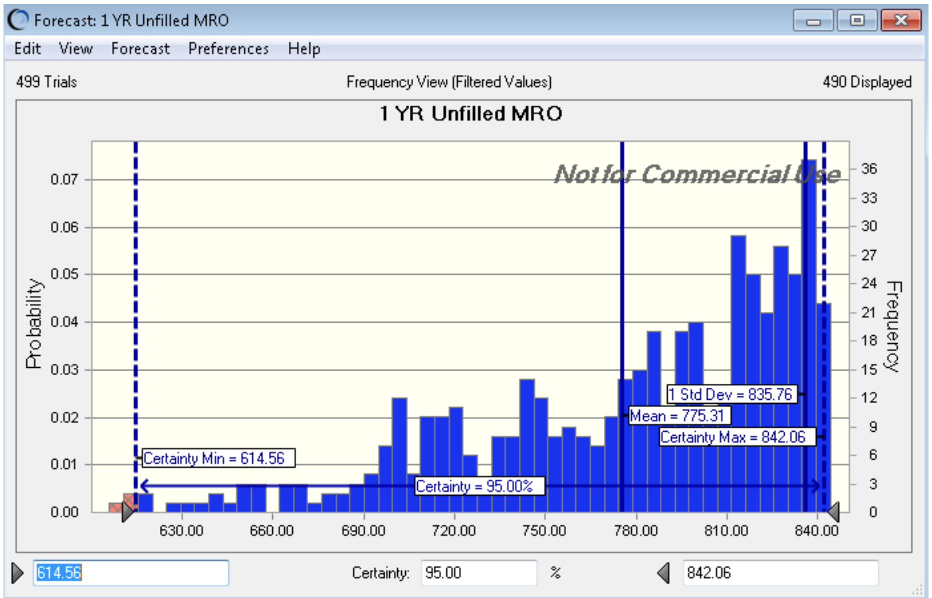


Figure 14. Left Tail of the Predicted Unfilled MRO for FY2013

After analyzing the data, over a 48 month period, there is a positive correlation between the total MROs and the percentage that is unfilled. By multiplying the percentage of MROs that are unfilled, we were able to plot the trend to show the correlation as demonstrated in Figure 15. As the total number of MROs decreases, the percentage of unfilled MROs also decreases. Not only does the number of unfilled MROs decrease as a percentage, but the actual percentage decreases. This correlation tells us that as the workforce is less busy, there is less inventory loss, potentially because there is more time to search for inventory and also they may make fewer errors. This is a key point for the DLA to consider. It suggests that if the DLA predicts workload will continue to decrease, the value of auto-ID technology for preventing inventory loss may decrease. Conversely, if the DLA predicts that workload will increase, the value of implementing auto-ID technology should increase.

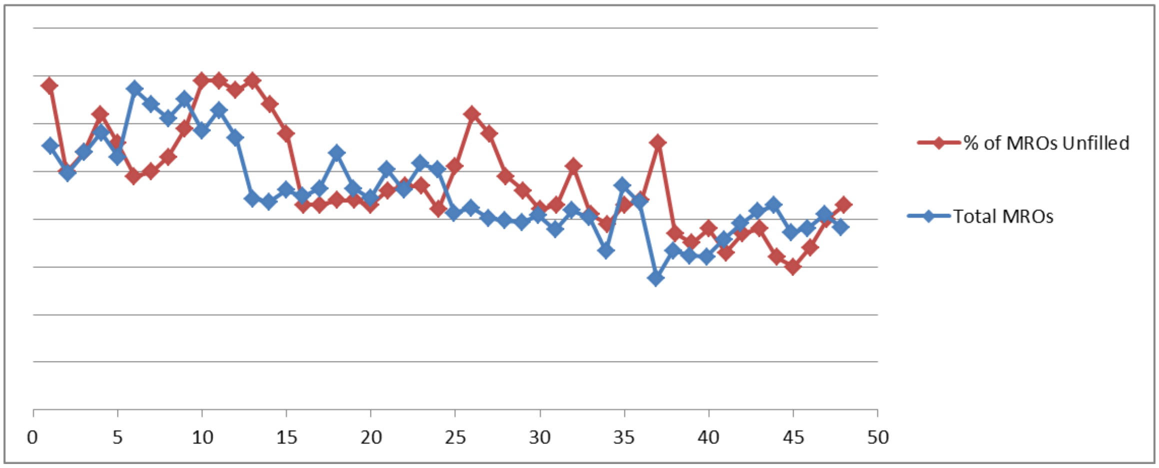


Figure 15. Correlation of Total MROs and Unfilled MRO %

The actual cost of the unfilled MROs was not available for this study. In order to assign an estimated cost savings provided by a reduction to unfilled MROs, we needed to develop a rational cost estimate of unfilled MROs. We developed a range of assigned values based on three factors: total number of items ordered in FY2014, percentage of total inventory by type (bin, bulk, and rack), and a percentage of total cost by type. Our first step determined the cost per item. We allocated a percentage of cost to the $10.8 billion in FY2014 inventory to each of the different types of inventory. We don't know the actual cost of unfilled MROs. In order to develop an estimate for an expected benefit, we calculated a value based on an estimated average cost of lost items. Our calculated average price per unit may actually be an overstatement. For simplification, bulk and rack were combined into one category of cost, giving us only two variables: bin and rack/bulk, shown in Table 25.

Table 25. Estimated Average Unit Price

Per Item (BINS)	Per Item (R/B)	
$55	$85	25% of Inventory Cost allocated to Bin Items
$75	$75	Even Weight between BIN and Rack/Bulk
$165	$28	75% of Inventory Cost allocated to Bin Items

We then assumed that 98% of the unfilled MROs were bin items. These items are smaller and easier to misplace. The remaining 2% of unfilled MROs is allocated as rack/bulk items. Though not likely misplaced, the potential for user error in out-processing exists. Multiplying these two percentages by 14,043, the number of unfilled MROs from FY2014, we developed an estimate of how many items were lost from each category. With this data, we were able to develop an annual cost based on low, average, and high cost estimates, shown in Table 26. These numbers are strictly estimates and may be substantially higher or lower. Our assumption is that with auto-ID, the DLA could eliminate unfilled MROs and therefore recognize these savings as a benefit.

Table 26. Estimated Cost of Unfilled MROs

	% of unfilled MROs	Number of items	Low	Average	High
# Bin	98%	13,711	$754,936	$1,026,713	$2,264,808
# R/B	2%	280	$20,953	$7,937	$23,811
	Total Annual Cost of unfilled MROs		$775,889	$1,034,650	$2,288,618

b. Sub-Analysis for RFID Implementation of only Highly Active Bulk and Rack Storage

In order to determine the savings from reducing the requirement to conduct inventory audits in the rack and bulk areas, we needed to determine what percentage of that inventorying expense is allocated for these areas. If the distribution of items remains constant by storage location, bin/rack/bulk, our assumption is the mean percentage of inventory can be used to determine an annual cost of inventorying bulk and rack. Based on receipts for the past three years, the averages for each location were 49% bin, 21% bulk, and 30% rack. To determine the allocated cost, the sum of bulk and rack, 51%, was multiplied by the total cost estimate for conducting inventories.

Estimated inventorying costs × % of inventory = allocated inventorying expense
$1,353,500 × 51% = $690,285

Our assumption on potential reductions of inventory auditing requirements between 75% and 95% was applied. This provided a range of potential savings (see Table 27).

Table 27. Potential Savings in Inventorying Auditing Costs (Partial)

Reduction		
75%	85%	95%
$517,714	$586,742	$655,771

In order to assign an estimated cost savings provided by eliminating unfilled MROs for the bulk and rack storage areas, the 2% calculated cost of unfilled MROs for bulk and rack was used from the previous calculations, as highlighted in Table 28.

Table 28. Estimated Cost of Unfilled MROs: Bulk and Rack

	% of unfilled MROs	Number of items	Low	Average	High
# Bin	98%	13,711	$754,936	$1,026,713	$2,264,808
# R/B	2%	280	$23,811	$20,953	$7,937
	Total Annual Cost of unfilled MROs		$778,746	$1,047,666	$2,272,744

c. *Other Benefits Not Included*

There are three benefits that we chose not to include in the NPV analysis due to a lack of sufficient information to generate a supportable assumption. These items fall into one of two categories, tangible or intangible benefits. These benefits are:

1. A reduction in labor hours during the customers induction process
2. The value of information to both the DLA and the DOD
3. The value of accurate inventory information to the EDC and the DLA

There also may be secondary tangible benefits that are received that were also not possible to assign a value to.

One of the tangible benefits not included is the potential savings in labor hours that can be experienced by customers. This benefit would be a reduction to in-processing time when items are received from the DLA. Based on our experience, our assumption is that implementing a form of auto-ID will reduce the amount of time required to receive items into supply and maintenance activities.

Our estimate is that an average of two minutes can be saved per item, by automatically populating all of the data into the system including where the part or supply is supposed to go. We used this assumption to calculate the potential costs in reduced labor hour savings across the DOD on inventory coming from just the EDC. Using the weighted hourly wage rate of $13.52, multiplied by the number of items at the EDC, we determined a potential savings of $47,266,339 annually, shown in Table 29. Calculating the potential savings outside of the DLA demonstrates a "split incentive." This term refers to the incentive for the adoption of RFID split across different DOD units (Coughlan, Dew, & Gates, 2008).

Table 29. DOD Wages Saved by Reduction in Required Labor Hours

DLA Items	Minutes Saved	Total Minutes Saved	Total Hours Saved	Wage Savings
104,876,144	2	209,752,288	3,495,871.46	$47,266,339

There also would be an associated cost to provide the Auto-ID equipment across the DOD. To realize this savings with an RFID solution, we assume the costs to equip every unit within the DOD would be very high. To calculate this cost, the data on the number of systems required for the DOD, the type of system, and the systems cost, are needed in order to accurately assign a total cost. Since we had insufficient data to develop the implementation cost, we did not include the potential savings as a benefit in our net present value for each of the systems.

One of the most difficult benefits to calculate in terms of monetary figures is the value of information. In a MBA project titled *The Value of Logistics Information to the Warfighter*, Corrigan & Kielar (2004) developed a value of information after surveying supply officers from naval aircraft carriers. From their surveys, they estimated that carrier activities were willing to spend "2.46% of their annual budgets for logistics information for high and low priority material while deployed" (Corrigan & Kielar, 2004). Their analysis identified an intrinsic value to logistical information to the warfighter. With accurate logistics information, various logistical and maintenance activities are more accurately able to determine both where to order their parts from and assess an approximate timeframe for receipt. The EDC's rate of unfilled MROs represents a problem that is experienced across the DOD when ordering parts. Activities potentially lose valuable time when ordering parts or supplies under the auspices that it is available from the DLA only to find later that it is not. These activities then must either choose to wait for the DLA to acquire new inventory or cancel their order and seek the part on the open market, potentially at a higher cost. From our experience, it is sometimes better to pay more on the open market and receive accurate tracking information from FedEx or DHL, and avoid ordering from the DLA altogether when it is a priority part or supply. The opportunity costs to the DLA are potentially very high; however, with the data we had available, we were not able to calculate these opportunity costs. Using the estimate of $856,775 made by Corrigan et al. (2004) for a single aircraft carrier, it is easy to see that this number could be several orders of magnitude higher for all of the DOD.

There is also a value in having more accurate inventory information to the EDC; however, it is difficult to develop a supportable assumption in terms of this tangible value. With accurate information, the EDC could reduce inventory-holding costs, experience fewer stockouts,[5] reduce shrinkage, provide better customer service, and finally decrease the opportunity loss from customers purchasing outside of the DLA. The EDC averages 114 million items valued at $10 billion in new inventory annually and currently holds approximately 300 million items. Holding costs are very substantial. If the DLA was able to reduce inventory holding at the EDC by 10% and they have $30 billion in inventory, there could be a $3 billion annual savings.

3. NPV Analysis

All NPVs were calculated over a period of 10 years.

a. Full RFID Implementation

The cost data for full RFID system implementation and the associated estimated annual costs for tagging and replacement of hardware was used for this NPV. As we had a range of two variable benefits (inventory labor hour and reduction to unfilled MROs),

[5] Stockouts: an event that causes inventory to be exhausted and demand for an item cannot be fulfilled.

we determined that the NPV for a full RFID implementation for the EDC would be a minimum of -$302,546,477, maximum of -$286,997,238, and mean of -$296,166,584, as shown in the following table.

Table 30. RFID NPV Sensitivity Analysis

NPV Range	
Mean	-$296,166,584
Standard Error	$2,043,448
Median	-$298,956,038
Standard Deviation	$6,130,344
Sample Variance	3.75811E+13
Kurtosis	-1.545158727
Skewness	0.714485604
Range	$15,549,239
Minimum	-$302,546,477
Maximum	-$286,997,238
Sum	-$2,665,499,258
Count	9

In order to receive a positive return on investment in 10 years, the value of uncalculated tangible and intangible benefits must be equal to approximately $36 million dollars per year at a 2.5% discount rate.

b. NPV for Full 2D Barcode Implementation

The cost data for full barcode system implementation and the associated estimated annual costs for tagging and replacement of hardware was used for this NPV. As we had a range of two variable benefits (inventory labor hour and Reduction to unfilled MROs), we determined that the NPV for a full barcode implementation for the EDC would be a minimum of -$99,226,180 and a maximum of -$83,676,941 with a mean of -$92,846,288, as shown in the following table.

Table 31. Barcode NPV Sensitivity Analysis

NPV	
Mean	-$92,846,288
Standard Error	$2,043,448
Median	-$95,635,742
Standard Deviation	$6,130,344
Sample Variance	3.75811E+13
Kurtosis	-1.545158727
Skewness	0.714485604
Range	$15,549,239
Minimum	-$99,226,180
Maximum	-$83,676,941
Sum	-$835,616,589
Count	9

In order to receive a positive return on investment in 10 years, the value of uncalculated tangible and intangible benefits must be equal to approximately $12 million dollars per year at a 2.5% discount rate. Barcode systems are cheap, unlike RFID, and their usage is a common practice. In comparison it would cost the DOD very little to equip all units with barcode readers. It then becomes feasible to include the other uncalculated benefits from page 68, making it is easy to assume that there would be a system-wide net benefit from implementing barcoding.

Potential Annual Benefit: $47M annual for reduced labor at other DOD sites + value of information ($856,775 from Corrigan et al., 2004) + potential EDC inventory savings ($3 Billion at 10% of total inventory costs) = $3.04 Billion Annually

c. NPV for Sub-Analysis for RFID Implementation of Highly Active Bulk and Rack Storage

We did not conduct a sub analysis for barcoding as it is our understanding that under the current processes, these items are already tagged with barcodes. For this sub-analysis for RFID Implementation of Highly Active Bulk and Rack Storage, the categories for cost and benefits are the same as in Case #1 and #2. The cost data for highly active bulk and rack storage system implementation and the associated estimated annual costs for tagging and replacement of hardware were used for this NPV. As we had a range of two benefit variables (inventory labor hour and reduction to unfilled MROs) with range, we determined that the NPV for RFID tagging bulk and rack storage items in the EDC would be a minimum of -$89,923,389 and a maximum of -$85,673,726 with a mean of -$86,935,182, as shown in the Table 32.

Table 32. Bulk and Rack Storage RFID NPV Sensitivity Analysis

NPV	
Mean	-$86,935,182
Standard Error	$449,387
Median	-$86,643,252
Standard Deviation	$1,348,160
Sample Variance	1.81754E+12
Kurtosis	2.461493814
Skewness	-1.445359922
Range	$4,249,662
Minimum	-$89,923,389
Maximum	-$85,673,726
Sum	-$782,416,636
Count	9

In order to receive a positive return on investment in 10 years, the value of uncalculated tangible and intangible benefits must be equal to approximately $10.25 million per year at a 2.5% discount rate. Intuitively it would seem that the NPV for this option would be much higher; however, implementation costs are still very high, and due to our assumption that this category comprises only a small percentage of the unfilled MROs, there is a much smaller benefit in their reduction.

D. COMPARATIVE ANALYSIS

The largest calculated factor affecting the sensitivity of all NPVs is the assigned value for unfilled MROs. Additionally, changes in the number of new inventory receipts will have a substantial impact on total cost over 10 years.

When analyzing each of the NPVs, there is an obvious disparity between the values that the non-calculated benefits must equal in order to provide a positive ROI within 10 years. Though 10 years is a short timeline at a 2.5% discount rate, we chose this as current technologies are always changing and new technologies evolving. 10 years from now, there may be a new technology that is even better.

The difference between a partial RFID implementation for highly active bulk and rack items versus an EDC-wide implementation of 2D barcodes is approximately $1.5 million dollars, while the difference between full 2D barcode implantation and full RFID implementation is approximately $25 million dollars annually. A determination with more accurate figures needs to be conducted in order to determine what the real value of the uncalculated benefits for each is. Our assumption is that these items are of generally higher value than bin storage items. Our chosen discout rate is .5% different than the OMB-94 rate for FY 15 budget year; however, this discrepancey doesn’t materially effect the outcome of our analysis.

Table 33. Comparison of Analysis

	Full RFID Implementation	Full 2D BC Implementation	Sub-Analysis for RFID Bulk/Rack
Implementation Cost	$124,181,050	$76,518,921	$2,360,624
Estimated Max 10yr Labor Savings	$13,452,571	$13,452,571	$10,451,294
Estimated 10yr Unfilled Max MRO Savings	$22,727,444	$22,727,444	$79,369
Mean NPV	-$296,166,584	-$92,846,288	-$86,935,182
Includable Other annual Savings*	-	$47,000,000	-
Remaining Savings Required	$36M/yr at 2.5% discount rate	$0	$10.25M/yr at 2.5% discount rate
* feasibly included other uncalculated benefits from page 68			

E. ANALYSIS OF ROBOTIC SOLUTIONS

Identifying the need for efficiency and visibility throughout their warehouses, the DLA could benefit from robotic technology such as Kiva. Like Zappos and Amazon, the DLA operates very large warehouses that store millions of units of inventory. Kiva robots and their vertical lift solutions would be ideal for the DLA because the robots would allow DLA to maximize space and offers a quicker and more efficient way to retrieve items that are stored on multilevel platforms through their warehouses.

As demonstrated by Zappos, this solution could be implemented quickly and could be designed and implemented in phases throughout the warehouse until the warehouse is completely re-automated. Lobosco (2014) pointed out that “once the system is in place, it can save time and cut down on fulfillment costs.” By utilizing robots, barcodes, and software, the DLA could improve and have greater visibility of the inventory within the warehouse. This would allow them to become more productive and fulfill requisitions more efficiently and accurately while decreasing lead-time and cycle-time. By having an efficient and accurate system like Kiva, the DLA could potentially decrease their inventory levels, which could drive down their inventory carrying cost. These types of changes could really help the DLA reduce their inventory footprint while modernizing and improving existing warehouses.

Cost savings could be achieved by this technology due to energy savings, training cost, and reduction in amount of labor required in the warehouse. Energy savings will be seen by not having the need to provide climate control for an 800,000 square foot warehouse. Climate control would only be needed in areas where people actually work. The need to have the lights on at all times would be eliminated because the robots do not need light; therefore, the only lighting required would be where people work. This type of solution would eliminate the need for conveyors that run 24 hours a day as well as the inventory carts that are pulled throughout the warehouse on a 24 hour, seven days a week basis. Both of these systems are critical in DLA warehouses, and both of them are extremely hard to keep operational. Not only are they hard to keep working, should either of these go down for more than a few hours, warehousing operations are disrupted and can come completely to a halt.

A robotic system could also provide a decrease in safety incidents throughout the warehouse. Having an environment that is clear of forklifts, conveyors, ladders, inventory carts, and golf carts would eliminate common safety incidents that ultimately cost a lot of money.

Determining the return on investment with RFID and robotics in a warehousing environment is very challenging due to the high cost of implementing the system as well as performance of the system due to required methodologies and processes. The cost associated with new technology is very high due to the research and development of the technology and the proprietary nature that allow the developing company to have little to no competition. This drives the price of product up as well as the components that make up the system. In RFID, it is the cost of software, tags, printers, and readers. Even after purchasing the software and hardware to utilize the system, there is the ongoing purchasing of the expensive tags. Dew and Read (2007) pointed out that "a new technology becomes available but if users do not adopt the technology in sufficient numbers because it is too expensive, vendors cannot produce it in the volumes necessary to make it less expensive" (p. 569). This is the case with RFID and robotics. Although both have been used within industry for many years, the cost to acquire and maintain the system is still high because there are not enough suppliers and users to promote competition and drive down the cost. There needs to be coordination throughout the industry to promote the adoption of RFID practices as well as robotics in order to increase demand and get the market to produce more products, which will ultimately drive down the cost and make it more affordable for companies to invest in the product.

The technology of RFID and robotics is very exciting and possesses endless possibilities in improving asset visibility not only in the warehouse, but across the whole supply chain spectrum. Using robotics in warehousing is not a new concept; however, the way robots are used within the warehouse environment and the procedures for using RFID have changed and can really provide improved efficiency. When new systems are implemented, new procedures, guidelines, and methodologies have to be adopted in order to maximize efficiency. This is an intangible benefit that is hard to measure and place value on. Once an organization adopts new technology and improves their own processes, most of these companies do not want to advertise to competitors the technology or processes that were put in place to increase efficiency resulting in their increased profits. This is a common problem throughout the logistics spectrum and is the reason why measuring the return on investment is very difficult. Companies have successfully integrated RFID technology and various robotic technologies; however, they now have a competitive edge. There is no incentive for them to advertise exactly how the system was deployed, the technology used, and what kinds of returns are being seen for their investment.

In order to truly understand what kind of return on investment that the DLA could achieve, it is vital to understand how other companies in the same industry with the same type of capacity measure their return on investment. In the article, "Match Your Innovation Strategy to Your Innovation Ecosystem," Adner (2006) defined an innovation ecosystem as "the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution" (p. 98). By collaborating with these other companies, the DLA could benefit by understanding the deployment strategies and would be able to determine if these technologies could provide benefit. Further, Adner (2006) pointed out that "when they work, ecosystems allow firms to create value that no single firm could have created alone" (p. 98).

The DOD has long been a leader when in adopting technologies. After Walmart mandated that their suppliers utilize RFID, the DOD followed suit as well as a number of Walmart's competitors to adopt this technology to achieve the same cost savings (Adner, 2006). As with RFID, now that there is a robotic solution being used successfully within the industry, the DLA should assume a leadership role in coordinating the adoption of robotic technology in warehousing to not only have asset visibility within the warehouse, but to coordinate and drive demand for more cost-effective robotic solutions as well as coordinating common knowledge. Taking on the leadership role does have challenges, and as Adner (2006) pointed out,

> Attempting to take the leadership role carries its own risk: It often requires massive resource investments over long periods of time before you find out whether the opportunity is real and whether you have managed to secure the orchestrator role. (p. 105)

As the United States draws down the wars in Iraq and Afghanistan, the high demand for products will decrease, which will allow the DLA to focus on the process improvements and implementation of robotics throughout their warehouses without negatively affecting the timeliness of logistics to the warfighter.

As the DLA takes on this role, the process of collaboration will show benefits throughout the industry. Dew and Read (2007) particularized that

> once the adoption cycle has begun, direct and indirect network externalities promise benefit to new and existing users in the form of:
>
> 1. reduced price as a result of standardization, scale, competition, and producer incentive to drive adoption
>
> 2. lower uncertainty regarding availability of future product version and upgrades
>
> 3. user population that provides informal support, content, and information sharing

4. higher quality products

5. a market for complementary goods, as well as scale and competition in that market

6. lower uncertainty regarding availability of future complementary products and services. (p. 570)

Within a large warehouse, the practices and procedures need to be reviewed thoroughly, updated, and implemented. If the process and procedures are not efficient, then robotic technology will not be effective or fix the process problem. The robotic technology would only be the implementer used to help to fix the process. If a company layers new robotic technology in a warehouse without changing the process, all they are doing is incurring more cost without gaining any benefits. Adner (2006) stated that “if an innovation is a component of a larger solution that is itself under development, the innovation’s success depends not only on its own successful completion but on the successful development and deployment of all other components of the system” (p. 99). We understand that people make mistakes; the purpose of the robot would be to eliminate those human errors. By adopting new processes and implementing robotic technology, a company can better understand the types of value that a robot could provide in the warehouse. For instance, Zappos has robots carrying inventory to a picker to put together an order. Having the robot retrieve inventory will reduce the labor cost of a picker walking around a warehouse, picking out items, and taking them to a person putting together an order. Not only is there a reduction in labor, but there is a reduction in the time it takes to retrieve the item and increases the amount of orders that can be filled each hour.

VII. CONCLUSION

For both cases and the sub-analysis, we calculated the cost of tagging all current inventory up front. This incurs a very high labor cost and tag cost in the first year. Tagging all current inventory with RFID tags during implementation is almost twice as costly as 2D barcoding. While significantly cheaper, RFID tagging only the highly active bulk and rack storage items return substantially less in terms of benefit.

For the RFID solutions, we did not include the DOD $47 million labor hour savings because we did not have the data available to assess what it would cost to implement RFID systems at all DOD units. 2D barcoding is far cheaper to implement and therefore easier to assess the $47 million DOD benefit due to its common usage and low cost.

Table 34. Comparrison for Conclusion

	Full RFID Implementation	Full 2D BC Implementation	Sub-Analysis for RFID Bulk/Rack
Implementation Cost	$124,181,050	$76,518,921	$2,360,624
Estimated Max 10yr Labor Savings	$13,452,571	$13,452,571	$10,451,294
Estimated 10yr Unfilled Max MRO Savings	$22,727,444	$22,727,444	$79,369
Mean NPV	-$296,166,584	-$92,846,288	-$86,935,182
Includable Other annual Savings*	-	$47,000,000	-
Remaining Savings Required	$36M/yr at 2.5% discount rate	$0	$10.25M/yr at 2.5% discount rate
* feasibly included other uncalculated benefits from page 68			

Looking at our comparison of costs and benefits it is apparent that if DLA has to bear the full implementation costs up front, it is may not be worth implementing RFID at this site. Based on our analysis barcode implementation should prove worthwhile if modest other savings are achieved e.g., reduction in labor hours during the customers induction process, and savings from value of information to both the DLA and the DOD (page 68).

RFID is the future of asset visibility, but it is still significantly more expensive. Before implementing this technology, an organization needs to really consider what their goals at end state really are. Without a doubt, RFID is an employable option; however, it potentially may take longer to realize a positive return on investment, depending on the tangible and intangible benefits, for a particular organization. For the DOD, it is a difficult decision.

One of the greatest benefits to both technologies is process improvement. Neither technology can be implemented without reviewing the current processes and making them more efficient. During our research, we made several findings that were related to the question of how efficient the current procedures are, but further research in terms of data, survey, and observation of processes needs to be conducted. Implementing RFID and robotic technology would give the DLA an opportunity to examine their processes and procedures and force them to adopt new procedures in order to efficiently use these new technologies. This is a benefit that cannot be quantified. As highlighted by Ferrer, Heath & Dew (2011)

> the payback from adopting an RFID system may come through its spillover effects which (a) are not a part of the business case analysis for implementing the technology, and (b) involve other process or technology changes in order to be realized. In short, a main cause of the difficulty in finding the ROI for RFID adoption may be because the payoffs lie in areas outside the scope of traditional payback models and may not be obvious without actually implementing the technology. (p. 620).

In our analysis, we briefly discussed that as demand decreases, the payoff for these technologies also decreases; however, there is more to consider. Investing now, can help prepare you for the future. As the demand continues to decrease, this would be an opportune time to implement these technologies and put together best business practices, so when demand increases again in the future, processes will be in place to ensure efficiency in distribution and effective asset visibility. There is a potential downside; the risk of overpaying as demand trends downward.

Unique 2D barcoding is cheaper and can provide a positive return on investment within the first few years of implementation. RFID is more expensive to implement now, however, the downward trend in costs of tags and system infrastructure, which we calculated at 6% in our NPV, alludes that beyond 10 years, this will return the greatest amount on investment in terms of reducing inventory-holding costs, experiencing fewer stockouts, reducing shrinkage, providing better customer service, and finally to decreasing the opportunity loss from customers purchasing outside of the DLA. Thus, this may be the best option. Either solution would require a complete process restructuring which will in itself help drive down costs. (Greve, 2008)

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VIII. RECOMMENDED FURTHER RESEARCH

In order to determine which technology would provide the most return on investment for the DLA, we recommend that the following research be conducted prior to a decision.

1. Determine what is causing the actual percentage of unfilled MROs to increase as total MROs increases with in the EDC. One would expect the percentage to remain constant and the number of unfilled to correlate to the total number of MROs. What we did not expect was for the actual percentage to increase as MROs increased and the inverse as to MROs decrease. A likely cause of this is either in the actual processes that are applied within the EDC or how personnel are assigned to augment the normal staff during increased periods of requests from customers.

2. Review the cyclic and annual inventory requirements and what they cost the DLA. In our research, we looked a regular inventories and causative research. We are not sure if this covers the required cyclic 10% inventories and annual 100% required by the DOD. These are the key costs that could be reduced through usage of auto-ID technologies.

3. Review all of the DLA's current processes to see what could be improved upon with auto-ID technologies. Without a complete understanding of the DLA's distribution processes, it is difficult to assign a savings in terms of process improvement. Our research proved a break-even requirement, but in order to make a final determination, a real number should be applied.

4. The DLA is already using RFID for certain applications. An example is pharmaceuticals and parachute storage in Susquehanna. An expansion in RFID into low turnover warehouses could decrease cycle counts which could provide a starting point for RFID implementation. Determine what RFID implementation and operating costs for low turn-over warehouses would be and what savings could be realized.

5. Get better data on value of information + cost savings for receipt of items elsewhere in Navy, i.e., the key costs we excluded from our analysis (page 68) but should be included from a system-wide perspective.

6. Calculated the sensitivity of costs and savings due to operational tempo increases and decreases.

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APPENDIX. TECHNOLOGY READINESS LEVELS

Table 35. Technology Readiness Levels (from DOD, 2011)

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or

TRL	Definition	Description	Supporting Information
		laboratory environment or in a simulated operational environment.	actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

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